

REDESIGN AND TEST OF A TWO-STROKE CYCLE
INTERNAL COMBUSTION ENGINE

A THESIS

Submitted in partial fulfillment
of the requirements for the Degree of

MECHANICAL ENGINEER

by

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Approved:

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Sub-Committee of Committee on
Advanced Degrees

PREFACE

The functions of a Mechanical Engineer have expanded during recent years to limits beyond those existing in the mind of the casual observer. These changes have been brought about by the increasing complexity of engineering demands.

Senate Bill No. 74, Acts Regular Session, 45th Texas Legislature:
An Act defining and restricting the practice of professional engineering in the State of Texas defines

"The term professional engineer shall mean a person who, by reason of his knowledge of mathematics, the physical sciences and the principles of engineering, acquired by professional education and practical experience, is qualified to engage in engineering practice such as consultation, investigation, evaluation, planning, designing or responsible supervision of construction in connection with . . . machines . . . when such professional service requires the application of engineering principles and interpretation of engineering data."

The above is a rather comprehensive statement but does not completely cover the functions existing during many relationships between an engineer and his client.

It is the purpose of the author to develop through references to his personal experience in practice some of the broader aspects of a Mechanical Engineer's expanded functions, as well as to show that this experience qualifies him as a Professional Engineer. This thesis will be limited to those experiences related to the investigation of an internal combustion engine model which resulted in the redesign of same into a test engine with rather peculiar limitations: (a) the principles

conceived by the inventor were to be rigidly adhered to, (b) the working capital at hand was limited, (c) the inventor and his brother were and are not familiar with general engineering principles and at times provided active opposition to the utilization of sound procedure.

It is not possible within the limitations of this paper to give sample computations of all the work necessary during the design. Certain of these calculations were done by Mr. Sherwood and are not pertinent. Some papers which contained calculations were lost by Mr. Sherwood and by Mr. Harold F. Shepherd.

The author wishes to acknowledge his appreciation for the assistance during the investigations, design and testing procedure of Mr. N. P. Sherwood, now director of research for Kiekhaefer Corporation, Cedarburg, Wisconsin.

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INTRODUCTION

In March, 1938, Mr. E. E. Heuschober of Fort Worth, Texas, requested that the author investigate his invention of an internal combustion engine. The idea of the engine as conveyed by his sketches failed to indicate anything of promise. Upon a subsequent visit, he displayed a small wooden model and extended an invitation to accompany him to Fort Worth and see the model engine. His progress up to that time is of interest as it bears upon subsequent work with him:

1. He had used the base, crankshaft, connecting rod and lubrication accessories of a second hand engine.

2. He used the "fit and try" method, making parts similar to those of the motor boat engine where possible, varying the design only where his conceptions dictated. Where a part was cut too large, he trimmed it down; where it was made too small, he discarded it and made a larger one.

3. His first assembly developed an interference, which cracked a head. The next few trials developed other difficulties. Eventually, he assembled parts which operated with moderate smoothness.

4. He disclosed his model engine to Mr. John W. Herbert, a Fort Worth oil operator, who contacted a testing laboratory in Austin, Texas. The quotation for a block test seemed too high to the inventor. Dr. Porter Brown, a physician in Fort Worth, suggested that the inventor contact Southern Methodist University for advice.

5. The engine was mounted on a lathe stand in the private machine shop in Fort Worth, in which he had done his time consuming labor.

Several weeks later the author visited this shop with the inventor, who cranked the model engine with ease and braked it with a plank applied to the flywheel. It stalled rather quickly. After starting the engine and observing its operation, the author dismantled it and inspected it thoroughly. Its simplicity was very evident. However, a number of reservations were made as to the correctness of certain principles.

The author returned to Fort Worth at a later date with a prony brake and made some rather rough test runs. Results of these were submitted to the inventor. The author accepted the inventor's proposition, which was to redesign the model engine, maintaining the original concepts, and, in every possible case using existing parts, thereby holding down the cost; to prepare only what blue prints were absolutely necessary; to supervise the assembly and test of a test engine; all in contemplation of the development of a commercial engine.

The author arranged to have a Southern Methodist University instructor, Mr. N. P. Sherwood, assist him on the project.

In this paper, the three engines will be designated as follows: (a) the model engine, Mr. Heuschober's; (b) the test engine, the author's design; (c) the commercial engine, the Lufkin engine.

At the outset, the author's contract was with Mr. Heuschober personally. Later it was transferred to the Heuschober Engineering Corporation. Under both arrangements it was necessary to work under strictest economy.

Mr. John W. Herbert, who had become financially interested in the Heuschober Corporation, wrote the author urging that a complete test be made with the model engine before any redesign was attempted. A photostat copy of this letter and of the report to Mr. Heuschober concerning estimates is included in this paper. (See page 4.) The figure of \$10,000 was based upon the assumption that the first design would not fully test the principles and that at least one or two revised designs would be required. Fortunately, the actual cost of the design, fabrication and test of one test engine was slightly over \$5,000.

The design and drafting were accomplished in about six weeks by the author and Mr. Sherwood. Pattern making, foundry work, machining work and assembly took about ten weeks. The author supervised these procedures and at times assisted in machining and adjustments. All of this work was done in Fort Worth.

Because of the opening of the fall session of Southern Methodist University, the test engine was set up in the Mechanical Engineering Laboratory at this school, where tests could be made conveniently in spare time by Mr. Sherwood and the author.

After reports of the tests had been submitted to the Board of Directors of Heuschober Engineering Corporation, Mr. Sherwood was employed by them to lay out the original plans for the commercial engine. After long negotiations, the commercial engine was licensed for manufacture to the Lufkin Foundry and Machine Company. Their chief designer was at that time Mr. H. F. Shepherd. According to Mr. Heuschober, only thirteen complete engines were built before

THURSDAY OF THE EDITION OF
JOHN W. HERBERT
REPRESENTING
JOHN W. HERBERT
REPRESENTING
JOHN W. HERBERT

PARK WEAVER
INVESTMENT COUNSEL

JOHN W. HERBERT
NEIL F. ANDERSON BLDG
FORT WORTH, TEXAS
PHONE 2-2221

REPRESENTING
OLIVER A. HERBERT
HAYES HERBERT KELLY

Page 2.
Prof. Ray M. Matson
4/6/38

April 6, 1938

Prof. Ray M. Matson,
3435 Aabury,
Dallas, Texas,

Dear Prof. Matson:

As you may know, I, in a small way, have helped Mr. E. E. Henschel in certain of his experiments and have received from him a small interest in his patents. He has discussed with me quite freely his contract with you which, incidentally, I think is excellent and fair to both parties and Mr. Henschel has also shown me your letter wherein you state that you think it would take some \$10,000. to engineer his idea to a point where it would be commercially ready for the market.

In this, I agree with you as to the amount, but feel that the method of approach suggested by you is possibly a little difficult from the standpoint of financing. In other words, it seems to me that it would be easier to first finance the proving of the theory of Mr. Henschel's invention and then secondly, finance the refinement of that theory to a point where it will be commercially ready for the market; rather than to try to take the two steps at once.

It seems to me that the first step to be taken is to find out by brake test the horse-power that the Henschel engine is a definite advancement over present two and four cycle engines, which proving I should think could be done for \$500.00 or \$1,000.00.

After the theory has been proven, then it will be very much easier to interest men with money to finance the refining of that engine to a point where the engine will be ready for manufacture and for sale, as it will be extremely difficult to interest men with money to the extent of putting up \$10,000.00 at this time to do both things without having pretty definite proof that the theory is sound.

If after thinking this over, you agree with my line of reasoning, don't you think it could be better to take the model that Mr. Henschel already has and work the variables out to a point where we know what efficiency we may expect before trying to go beyond that point, and properly engineer completely engine which would probably stand up on a 1,000 hour full load brake test, as the model engine might very well give us the efficiency data and still

have weak points in it from the stand-point of connecting rod bearings, ignition cooling, or one hundred and one other details which might cause the engine to fall on a long brake test, but which would in no way take away from the knowledge that the basic theory was correct.

Very sincerely yours,

/John W. Herbert.

jwh-s

3435 Ashbury,
Dallas, Texas.
April 2, 1938.

Mr. E. E. Henschel,
2045 6th Avenue,
Fort Worth, Texas.

Dear Mr. Henschel,

I have been considering the matter of development of your two-stroke cycle internal combustion engine as to the probable cost of the preliminary work.

If this development were to be made by a research organization with rather high overhead and high salaried specialists, the cost could easily amount to \$25,000.00. However, I believe that if you were to be in personal charge of the expenditures and had a experienced machinist to do exactly as you specify and with the advice of engineers willing to work at a moderate salary and without overhead to unduly increase costs, the investigation could be made for very close to \$10,000.00.

As I stated to you last week, I have several friends in the fire. But I am interested in the idea which your engine presents and would be willing to change my plans for the summer and work with you on your engine, if I were assured that you had at your disposal approximately the above amount for necessary expenses of the building and testing of an engine of one or two and certainly not over four cylinders.

Do not understand me as saying that I am certain that your engine will prove to be all that you hope. I can only say that if and when the tests are completed. But the idea seems to have very fine possibilities.

If you are able to assure me that the above amount will be available, I should like to know within four or five weeks so that I can notify the parties I have been in correspondence with and not hold them in suspense.

Very truly yours.

Ray E. Watson, Head,
Department of Mech. Eng.
Southern Methodist University,
Dallas, Texas.

priority on certain materials caused cessation of production. Lufkin turned their attention to war contracts upon which priorities were not so strict.

INVENTOR'S MODEL AND ITS PRINCIPLES

The inventor presented to the author the principles as outlined below, using a wooden model with a sliding piston moving in a slot on a wooden board, upon which the cylinder, head and base, were outlined in ink. It served to show his initial idea upon which the Heuschöber model engine had been built. This wooden model has since been broken and hence could not be photographed for this paper. The author has prepared drawings modified from the inventor's patent application. The modification is necessary because the patent application contains changes which resulted from the author's investigations and recommendations.

The invention related to internal combustion engines, particularly to the two-stroke cycle, with the purpose of providing a simple, inexpensive, durable engine having a minimum number of moving parts. It provided a means for the elimination of crank case compression with its dilution of lubricant, by utilizing an inside chamber to produce pre-compression of the air-fuel mixture. The accompanying turbulence would cause more complete mixing of air and fuel, and insure more complete combustion. It also provided cooling of the piston while preheating of the air-fuel mixture.

Figure 1 is an elevation of the model showing the piston in the head end position. Figure 3 is an elevation of the model showing the piston in the crank end position. Figure 2 is a plan view of the cylinder and piston.

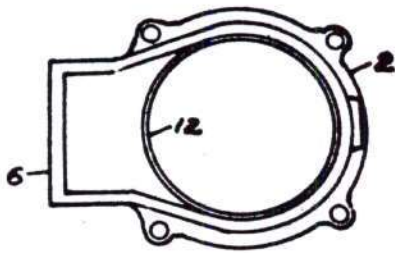


FIGURE 2.

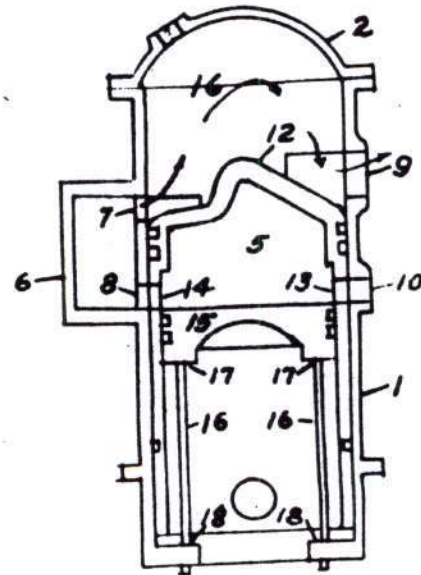


FIGURE 3.

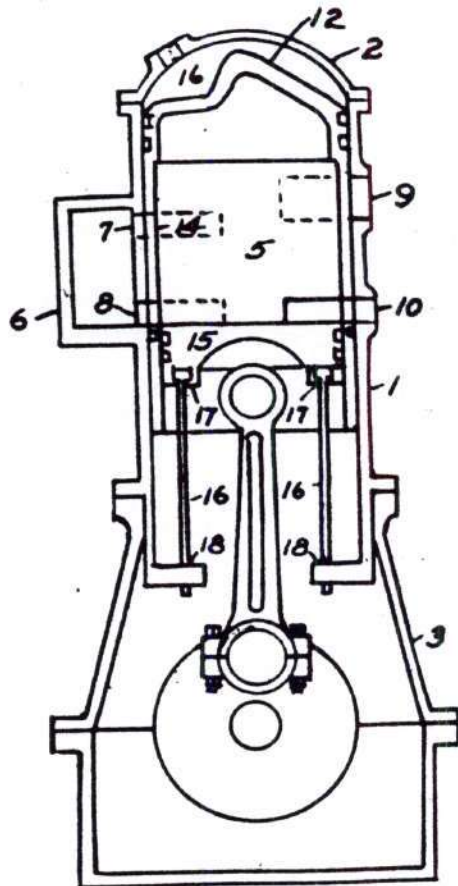


FIGURE 1.

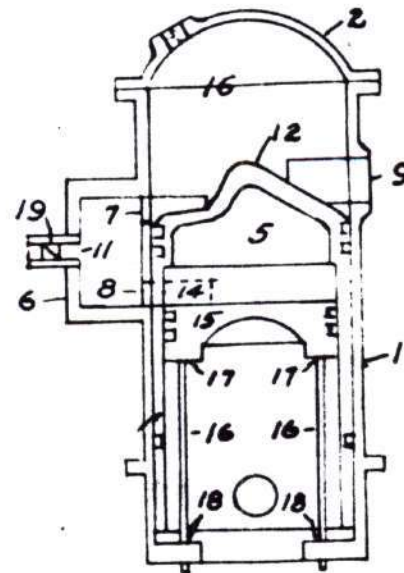


FIGURE 4.

The engine consisted of a cylinder 1, a removable head 2, and a crank case 3. The cylinder was provided with a by-pass chamber 6 positioned on the side thereof and formed integrally with the cylinder so as to register therewith at two ports, 7 and 8. On the opposite side of the cylinder 1 from the by-pass chamber was an exhaust port 9 and an intake port 10. The exhaust port 9 and the intake port 10 were provided in the cylinder 1 with the exhaust port on top. The by-pass chamber 6 was formed to extend almost one-half of the circumference of the cylinder. (No device was provided for the varying of the by-pass displacement volume.) The piston 12 of the motor was provided with a relatively long skirt. A disk shaped member 15 was rigidly positioned upon the motor frame so that it would telescope into the skirt of the piston 12 and served to form a chamber 5 inside the piston 12. This disk was supported by a pair of columns 16 attached to disk at 17 and to the frame at 18. When the piston 12 was in its uppermost position in the cylinder, as shown in Figure 1, fuel mixture passed through the intake port 10 of the cylinder and into the chamber 5. A port 13 was provided in the skirt of the piston 12 which registered with port 10 of the cylinder 1. As the piston passed downward to the crank end position in the cylinder, the mixture in the chamber 5 was forced into the by-pass 6 through first the ports 14 and 7 and then through port 14 of the piston registered with the port 8 and allowed the air-fuel mixture to pass through the by-pass 6 into the combustion chamber 16 by way of the by-pass port 7 and over the top of the piston as shown by the arrows in Figure 3. The exhaust port 9 has been uncovered and the fuel mixture entering will force out the burned gases, scavenging the

cylinder. The inventor claimed that the air-fuel mixture drawn into the chamber inside the piston not only would cool the piston head but also would more completely vaporize the air-fuel mixture before it passed into the combustion space.

PRELIMINARY SURVEY OF THESE PRINCIPLES

The author had agreed and signed a contract to develop the test engine based upon the inventor's principles. After some more carefully conducted calculations and sketching of layouts (since the writing of a paper on the subject was not contemplated at that time, these layouts and calculations were not preserved), it seemed that the port 10, Figure 1, could not be made ample to pass sufficient air-fuel mixture to develop maximum output. The time for flow of mixture through port 10 was limited to the time that it would register with port 13 in the piston wall. Also the exhaust and intake ports were on the same side of engine, limiting the height of port 10 and suggesting the probability of congestion of equipment and some considerable inconvenience in installation. The inventor asserted emphatically that the simplicity claimed for his principle would be invalidated by any deviation from his original concept. His brother, who had become financially interested, supported him. Mr. Sherwood supported the author's contention.

The author spent some time in working out a number of alternate arrangements. The one that appeared most logical was most simple. At length it was agreed to run a simple prony brake test on the model engine and then make the suggested change and run a similar test. The inventor acquiesced. Mathematics and formulae and suppositions as to installation convenience were meaningless, but a performance test appealed to him. The comparative tests showed an increase of 50% in developed horsepower with the suggested change. (Original arrangement, 1.2 horsepower at 1000 r.p.m.; substitute arrangement, 1.8 horsepower at 1000 r.p.m.)

The inventor enthusiastically agreed to abandon the original arrangement and accept the substitute.

The substitute arrangement merely called for closing up port 10, Figure 1, and placing an opening 11, Figure 4, in the by-pass chamber 6. The opening 11 was supplied with a check valve 19 leading to a carburetor. As the piston moved upward during the compression stroke of the engine, the inner chamber 5 was enlarged causing a lower pressure, which caused the check valve 19 to open and pass the charge of air-fuel mixture into the by-pass chamber 6 and on through ports 8 and 14 into the inner-piston chamber 5. This suction operation could occur during the whole time from the closing of port 7 until the piston reached top dead center. Upon the beginning of the downward or power stroke of the piston, the pressure in the inner-piston chamber 5 and the by-pass chamber 6 became greater than atmospheric and the check valve 19 closed. All other virtues of the inventor's principle were retained, and the disadvantages, starving of the engine and congestion of space, were eliminated.

Another feature of the inventor's model engine which caused concern was that of the proper volume for the by-pass chamber 6. Since the model engine was so constructed that no data concerning temperatures and pressures in the internal and by-pass chambers as well as in the cylinder itself could be measured, the only avenue available was that of making some conservative guesses. A number of trial calculations with maximum and minimum combinations of temperatures and pressures were made by the author. From these, limiting volumes were computed. Then the author proposed building upon the by-pass side of the test engine a variable volume chamber which could be varied and used to determine the proper by-pass volume for best performance. This device

contributed valuable information during extended study by Mr. Sherwood and Mr. H. F. Shepherd of Lufkin Foundry and Machine Company in the layout of a commercial engine.

Another element in the inventor's model engine where improvement seemed probable was in the matter of determining the proper size of ports: (a) intake port from the carburetor 11, (b) ports interconnecting by-pass chamber with inner-piston chamber 8 and 14, (c) intake port from by-pass chamber to combustion chamber 7, (d) exhaust port 9.

It seemed a sound procedure to use a number of removable plates each with a different size hole for (a), and to vary carburetor settings. A number of removable liners for the cylinder with varying sizes and positioning of holes seemed to be a logical procedure for (b), (c) and (d).

ORGANIZATION FOR PROJECT

It became necessary at an early moment to come to a decision in regard to such matters as size, speed, desired output, use of standard parts, allocation of the work to be done.

Since the Heuschober Engineering Corporation must of necessity operate upon funds derived from the sale of stock to local friends and associates of the inventor, the author used as many standard parts of other engines, purchasable on the open market, as seemed expedient in view of economy. For that reason, it was decided to use the engine base and crankcase of a small two-stroke cycle, crankcase compression, single cylinder engine, including its crankshaft, oil pump and connecting rod. This decision determined the size, $3\frac{1}{4}" \times 3\frac{1}{4}"$ engine. The crankshaft doubtless would not be dynamically balanced for the more elongated skirted piston demanded by the Heuschober principle. The speed set by the author for design calculation was 1000 r.p.m. Several other engines of similar size were analyzed and their ratings were corrected to this speed. From this analysis the design output for the test engine was set at 2.5 horsepower. The calculations which were made on this point are included in a later section.

The various parts of the work to be done by Mr. Sherwood and the author were allocated from time to time according to the nature of the work, the load at that time carried by each and the progress of the project. It was impossible to foresee in every instance the magnitude of the difficulties which might arise and to estimate accurately in advance the time that would be required to complete certain rational

developments. Basic investigations were made in most cases by the author who turned them over to Mr. Sherwood for routine analysis. A number of fine suggestions came from Mr. Sherwood, more as he grew into the investigations. In practically every case, these were left with him for analysis unless the author seemed better equipped for analyzing the elements involved. Drafting was done by both men. The greater part of the assembly and adjustments were made by Mr. Sherwood, who had better shop training and experience as a mechanic. The author handled calculations that involved thermodynamics, mechanics and machine design.

PRELIMINARY LAYOUTS

After the decision to use standard parts in an effort toward economy was made, the problem became that of designing all new parts to fit in a satisfactory manner. Complete sets of precision measuring instruments were not available at all times and some substitute methods were invoked. The connecting rod, which was purchased with the crank case assembly, was analyzed to determine its inertia effects. The rod was weighed on calibrated scales. Its center of gravity was determined by balancing on a knife edge. Its period of oscillation was determined by the laboratory method of suspending it on a knife edge and setting it in motion with a maximum deviation from the horizontal of 4.5 and determining the time for 20 cycles of oscillation. This operation was repeated 10 times and the average period was computed. The compound pendulum formula was used to determine the second moment of mass. From this value, the center of percussion was computed. The inertia effects of the elongated piston were calculated from estimated dimensions in the preliminary investigations. The dimensions of the crankshaft and the counter balance were measured, the masses were computed and the system was set up for graphical solution in accordance with principles outlined in Ham and Crane's "Mechanics of Machinery." This analysis indicated that some unbalance would exist. A notation was made to make a change in the counter balances if the engine when tested should vibrate excessively. The inventor's model engine did show violent vibration at speeds over 1000 r.p.m. Since the test engine was to be designed for

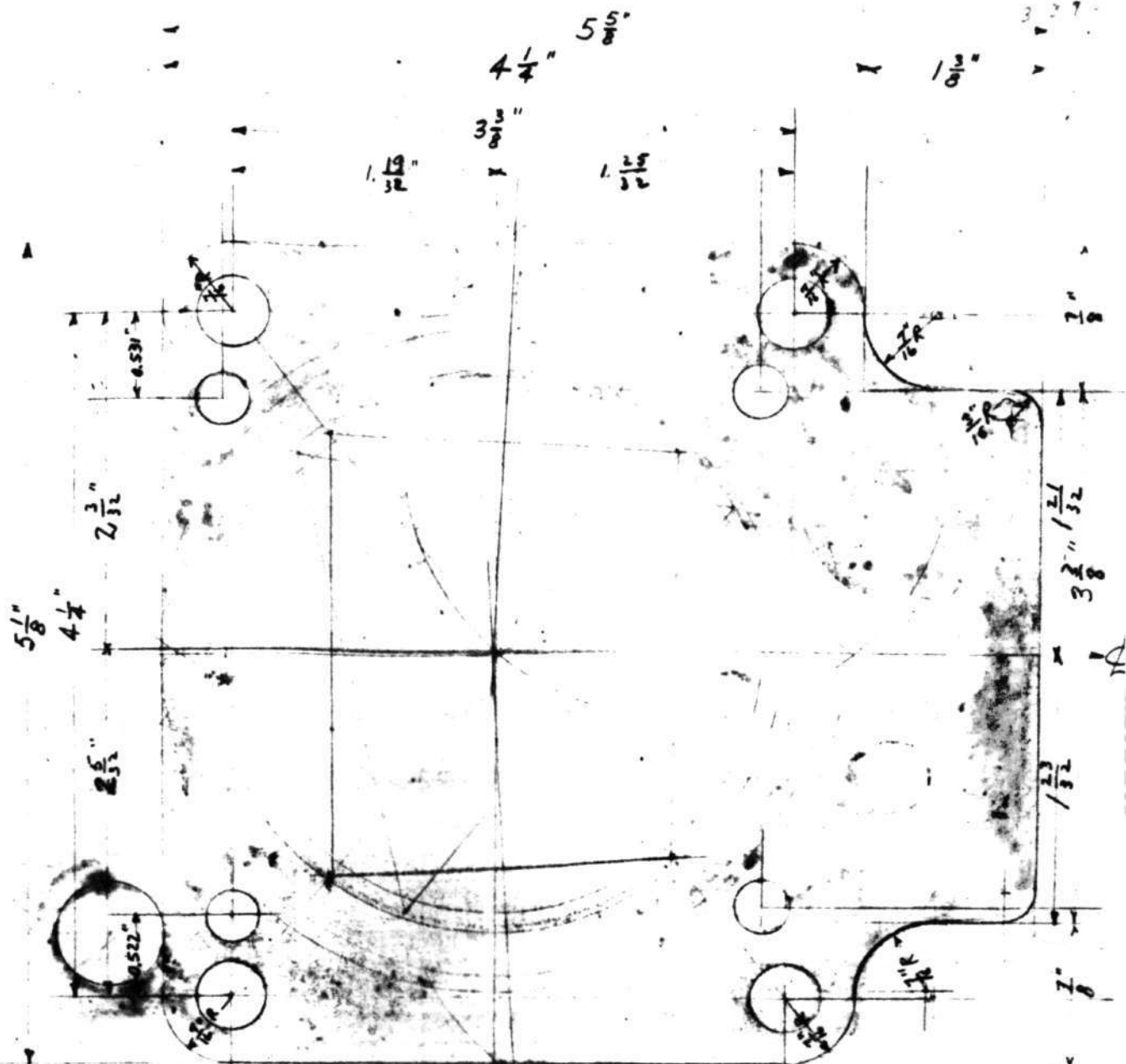
1000 r.p.m., no dangerous vibration was anticipated. Even at higher speeds during tests, the test engine ran in a stable manner.

The face plate of the crank case was slightly irregular in contour. A "rubbing," as it is often termed, was made of this surface and the cylinder casting was designed to fit. A photostat of this "rubbing" is shown on Page 18.

A spring loaded check valve assembly was found in a junk yard by Mr. Heuschober. This served satisfactorily as an intake valve between the carburetor and by-pass chamber. "Rubbings" were made of the faced surfaces of this assembly. The by-pass chamber was designed to fit and a special carburetor connection was laid out for casting. Fortunately, the springs of this check valve performed satisfactorily without redesign.

Of the many variations which were considered following the preliminary layouts, some seemed advantageous and were adopted. From step to step, the inventor insisted upon personally checking layouts in order to be certain that his original ideas were being maintained. And since he was the inventor, his ideas were always considered and used when feasible. The patience of the author was severely strained many times. In the cause of harmony, the policy of going carefully into each step with the inventor and finding explanations which would appeal to his reason was followed. His active imagination tended to jump afield from the principle at hand and at times delayed immediate progress.

$$\frac{1\frac{19}{32}}{2\frac{1}{2}} \quad \frac{1\frac{1}{16}}{2\frac{1}{2}} \quad \frac{1\frac{25}{32}}{2\frac{1}{2}} \quad \frac{1\frac{1}{16}}{2\frac{1}{2}}$$



"Rubbing" of blank base

DESIGN PROBLEMS AND THEIR TREATMENT

At the outset the author made an attempt to find out from authoritative sources some demonstrated principles for use in the design of the type of engine at hand. Dr. Ray L. Sweigert, of the Georgia School of Technology, was consulted at the meeting of the Society for the Promotion of Engineering Education at College Station, Texas, June, 1938. Dr. Sweigert suggested that the author write to Professor Ben G. Elliott, of the University of Wisconsin. After reading Professor Elliott's text, "The Gasoline Automobile," and finding no assistance, the author wrote him for suggestions. His associate, Professor E. T. Hansen, answered this letter. The desired information was not available. Photostats of the correspondence are included in this paper, pages 20 and 21. Neither the books by Counter nor the thesis Professor Hansen mentioned could be procured for use during the summer.

A similar request to Professor Howard E. Degler, University of Texas, received a similar reply. The suggestions made in his answer, photostat copy, page 22, proved to be of no assistance.

Attack on the problems in general was based upon assumptions of probable conditions and approximations as outlined in a number of examples to follow. Some source material gave suggestions of methods of attack. Credit is given as completely as possible.

George W. Hobbs, Ben G. Elliott and Earl L. Consoliver, "The Gasoline Automobile," Third Edition, 1924.

May 19, 1938.

Prof. Ben G. Elliott,
Department of Mechanical Engineering,
University of Wisconsin,
Madison, Wisconsin.

Dear Professor Elliott,

I am very much interested in getting a list of source material on two stroke cycle gasoline engine design. I am particularly interested in the design of ports, both intake and exhaust, particularly in regard to the proper sizes for economical results at various speeds of the engine and in regard to the best pressures for scavenging. I have found difficulty in finding any very definite information along these and other lines.

I am enclosing a stamped, addressed envelope for your reply. I would appreciate greatly any suggestions which you might make which would enable me to secure the above information.

I have your text on the Gasoline Automobile, but do not find quite the material on the two stroke cycle problems. I would appreciate your suggestions at your earliest convenience.

Very truly yours,

Ray M. Watson, Head,
Department of Mechanical Engineering,
Southern Methodist University.

RMM/m.

THE UNIVERSITY OF WISCONSIN
DEPARTMENT OF MECHANICAL ENGINEERING
MADISON

21

MECHANICAL ENGINEERING BUILDING
UNIVERSITY AVENUE

June 9, 1938

Prof. Ray A. Matson, Head
Dept. of Mechanical Engineering
Southern Methodist University
Dallas, Texas

Dear Mr. Matson:--

Your letter of May 19 to Prof. Ben G. Elliott requesting information on two-stroke cycle gasoline engines has been referred to me. My delay in answering has been caused by the usual press of work that comes at the end of the school year.

I doubt that I can give you the information desired. I became interested in this type of engine about a year ago, and was faced with the same problem. There is apparently very little design information on these engines published. The New York office of the Society of Automotive Engineers has a list of published papers on the subject, but whether it will give you the information you desire is a question. The only book on the subject that I know of is "The Two-Cycle Engine" by C. A. Caunter published by Sir Isaac Pitman and Sons, Ltd. of London in 1932. "Small Two-Stroke Aero Engines" by the same author was published in 1936. The first book gives some information on port design and timing with tables of values for English engines. The second book describes recent types of English aero engines.

During the last year I have been making a study of the cylinder and crankcase pressures of a 2-port and a 3-port two stroke cycle motor by means of a balanced diaphragm indicator. The motors were single cylinder, air cooled with a bore of $2\frac{1}{4}$ " and a stroke of $1\text{-}\frac{3}{4}$ ". While the work contemplated on the motors is not finished, the first phase, covering the characteristics of the two stock motors is reported in a thesis, a copy of which I shall be glad to loan you. Future work on the motors is to cover the effect of variation of air flow resistance and timing of the ports and variation of the crankcase clearance volume on the performance of the motors. When this is completed, I hope to have information on design of ports and timing for various speeds.

The thesis copies will be available in about two weeks, and I shall be pleased to send you a copy if you wish. If I can supply you with any further information, I shall be pleased to do so.

Yours very truly,

E. T. Hansen

DEPARTMENT OF MECHANICAL ENGINEERING

AUSTIN

April
Twenty-seventh
1938

Professor Ray M. Matson
Department of Mechanical Engineering
SMU University
Dallas, Texas

Dear Professor Matson:

It is likely that the information which you desire on the design of gasoline engines may be found in "The Gasoline Automobile, Its Design and Construction" by P. M. Heldt, Nyack, New York. He publishes these books under his own name and it is likely that if you can't find it in your local libraries that you will find it necessary to order direct. There are also several books on the gasoline engine published by McGraw-Hill Book Company and written by Elliott and others of the University of Wisconsin. The material which you are looking for on 2-stroke cycle engines will be hard to find, but the crank-case compression type used on marine installations may be what you are thinking about.

You will find a little information along these lines in the various design books by such persons as Norman and Maleev.

In this connection I am wondering if you are thinking about the 2-cycle gas engines which have recently had a new lease of life because of gas injection (under pressure) and improved scavenging. If you desire explicit information on the design of each of the component parts of a gasoline engine I believe you will have difficulty in finding all of it in one place. Some of this material is covered in my recent book on internal-combustion engines, but I would hesitate your referring to this for the complete design of all parts.

Hoping that this information will be of some value to you, and sorry that I could not be more explicit, I am

Cordially and sincerely yours,

Professor of Mechanical Engineering
Chairman of the Department

HED:et

The preliminary calculations for anticipated power output of the test engine at rated speed of 1000 r.p.m. with a 3 1/4" x 3 1/4" cylinder were made with the following assumptions:

The effective stroke was considered as that portion of the piston stroke which occurred from closing of the exhaust port to top dead center. $S_e = S_a - P_{ex}$. The effective clearance was then based upon this effective stroke. The effective displacement and the clearance volume were computed from the effective stroke and clearance, respectively.

Exponent $n = 1.30$; pressure at the beginning of compression stroke, $P_A = 15$ pounds / sq. in. Absolute; pressure at the end of combustion, $P_C = 300$ pounds / sq. in. Absolute; actual stroke, $S_a = 3.25$ "; exhaust port height, $P_{ex} = 0.5$ "; effective clearance $c_e = 25\%$.

$$\text{Effective stroke, } S_e = 3.25" - 0.5" = 2.75"$$

$$\text{Effective displacement, } V_{de} = (1.25)(2.75") = 3.438"$$

$$\text{Effective clearance volume, } V_{ce} = (0.25)(2.75") = 0.688"$$

Pressure at the end of compression,

$$P_D = P_C \left(\frac{V_C}{V_D} \right)^n = (300)(0.2)^{1.3} = 37.2 \text{ pounds / sq. in. Absolute}$$

Pressure at the end of the effective expansion stroke (as the exhaust port opens), $P_B = P_A \left(\frac{V_A}{V_B} \right)^n = (15)(5)^{1.3} = 122 \text{ pounds / sq. in. Absolute.}$

Then, the net work per stroke from the closing of the exhaust port to the opening of same (the pump work during the time of scavenging was neglected since it was assumed that this would be small as well as difficult to compute with certainty),

$$WK. = \frac{(P_C - P_B) \frac{V_c}{(1728)} \left(\frac{P_D}{P_C} \right)^{n-1}}{1 - n} = \frac{(144)(300-122) \left(\frac{5.7}{1728} \right) \left(\frac{37.2}{300} \right)^{0.3-1}}{(1 - 1.3)}$$

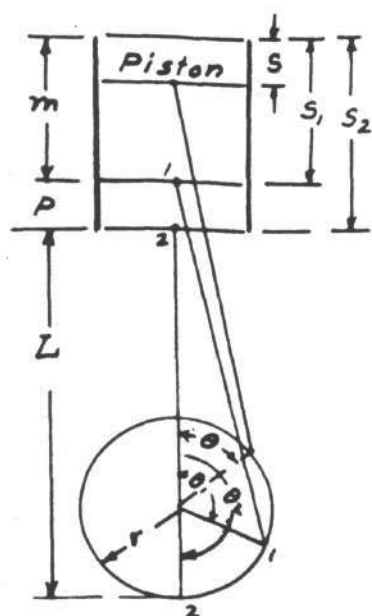


FIGURE 5a

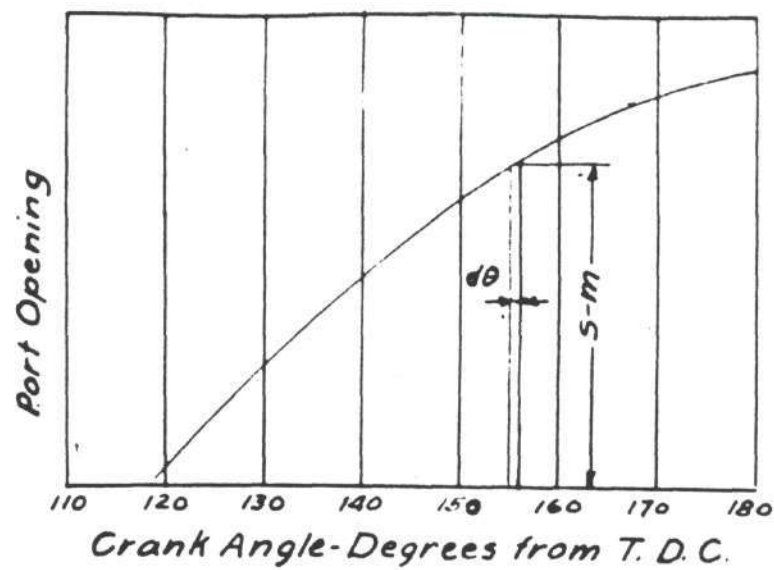


FIGURE 5b

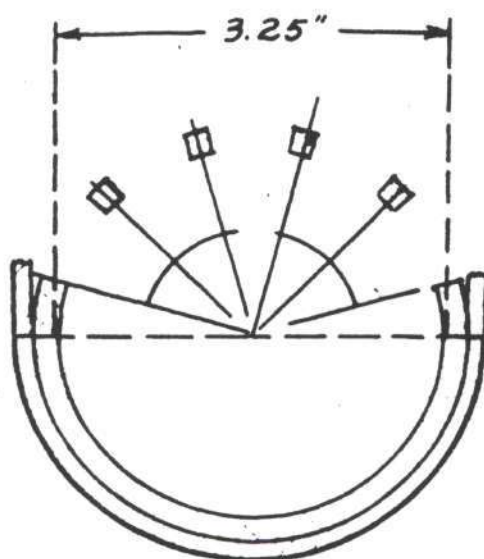


FIGURE 6

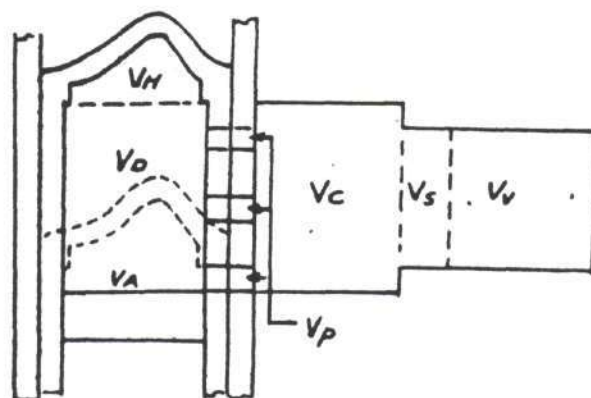
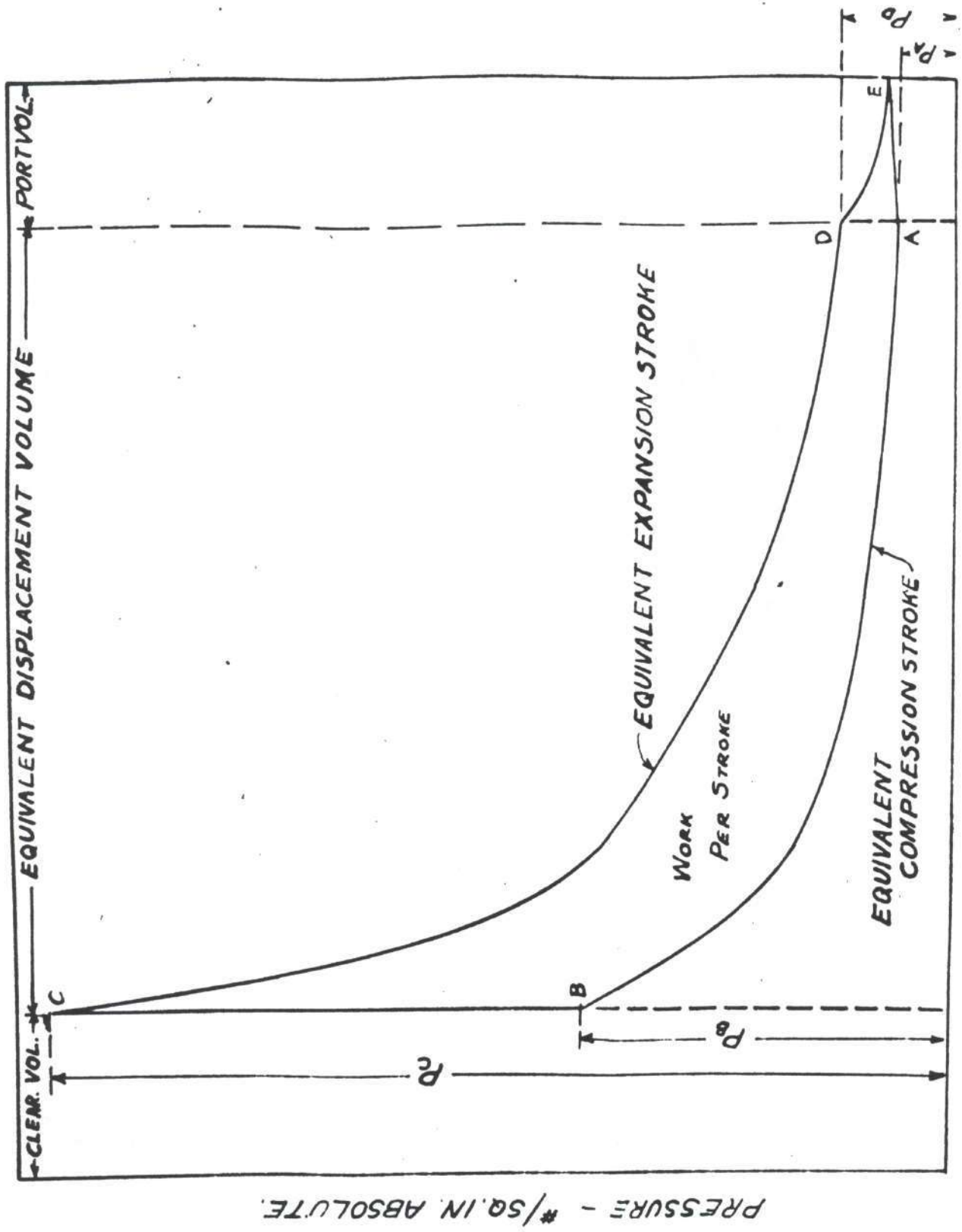


FIGURE 7



VOLUME - CU. FT.

FIGURE 8.

≈ 137 ft. pounds / stroke.

At 1000 r.p.m., the indicated horsepower

$$i.hp. = \frac{(137)(1000)}{33000} = 4.15 \text{ hp.}$$

At an assumed mechanical efficiency, $\eta = 85\%$, the calculated brake horsepower is

$$b.hp. = (4.15)(0.85) = 3.53 \text{ hp.}$$

The author advised Mr. Heuschöber that the assumptions were optimistic and that only 2.5 horsepower should be expected. Since this value was higher than the 1.8 horsepower that had resulted from the tests on the model engine with the intake port changed over, he was satisfied with the progress. Later, tests with natural gas as a fuel in the test engine showed results of 3.58 brake horsepower at 1000 r.p.m. corrected to standard S.A.E. conditions. However, these tests were under conditions which would not be existent in practice as outlined in the section, "Test Work and Reports."

The method of effective stroke and displacement used in the calculations is described by Hamilton, although he does not give it this name, nor apply it as herein proposed. This method was used also as a way of comparing other types of two-stroke cycle engines on a power per cubic inch displacement basis.

In the design of the intake port leading from the pre-compression chamber to the cylinder, reference was made to "Internal Combustion Engines," by Streeter and Lichty.

Erwin H. Hamilton, "Elementary Thermodynamics of the Automobile Engine," First Edition, 1922. pp. 195-197.
Robert L. Streeter and Lester C. Lichty, "Internal Combustion Engines," Fourth Edition, 1935. pp 388-390.

As in conventional types of engines, this port is opened and closed by the operation of the piston. The attached Figures 52 and 5b serve as illustration of the principles utilized. The port opening at any crank angle is determined graphically or analytically by laying out the position of the top edge of the piston with respect to the port (Figure 5a). The first part of the port to be opened is the last to close and remains open a greater length of time than any other part of the port.

The amount of air-fuel mixture that will pass the port at a certain pressure difference is governed by the port area and the coefficient of discharge. As the area is constantly varying, the mean port area for the period the port is open must be determined. Let the port openings be plotted as ordinates and the corresponding crank angles as abscissas (Figure 5b). The crank angles are proportional to time with a constant angular velocity of the crank. Integrating for the area under this curve and dividing by the diagram length results in the mean port opening. Multiplying this by the port width gives the mean port area.

The area under the curve in Figure 5a may be found as follows:

The port opening at a given crank angle depends upon the height of the port and the distance the piston moves from top dead center before uncovering the port. Let the distance from the top dead center to the top of the port be m , the distance the piston travels from top dead center for a given angle θ be s . When s is greater than m , the port opening will be $s - m$ as shown in Figure 5b.

The differential area, dA , is expressed as

$$dA = (s - m) d\theta$$

The total area under the port opening curve from θ_1 , the opening angle, to θ_2 , the bottom dead center angle, is equal to

$$A = \int_{\theta_1}^{\theta_2} (s-m) d\theta$$

s, the distance the piston travels from top dead center for a given angle θ is expressed as

$$s = r(1 - \cos \theta) + \frac{r^2}{4L} (1 - \cos 2\theta)$$

where r = crank radius

L = connecting rod length

$$\begin{aligned} A &= \int_{\theta_1}^{\theta_2} \left[r(1 - \cos \theta) + \frac{r^2}{4L} (1 - \cos 2\theta) \right] d\theta - m \int_{\theta_1}^{\theta_2} d\theta \\ &= r\theta - r \sin \theta + \frac{r^2}{4L} \theta - \frac{r^2}{8L} \sin 2\theta - m\theta \Big|_{\theta_1}^{\theta_2} \\ &= \left(r + \frac{r^2}{4L} - m \right) (\theta_2 - \theta_1) + r \sin \theta_1 - \frac{r^2}{8L} \sin 2\theta_1 \end{aligned}$$

since $\theta_2 = 180^\circ$, $\sin \theta_2 = 0$ and $\sin 2\theta_2 = 0$

$$A = K_1 (\theta_2 - \theta_1) + r \sin \theta_1 + \frac{r^2}{8L} \sin 2\theta_1 \text{ (inch radians)}$$

where $K_1 = \left(r + \frac{r^2}{4L} - m \right) = 57.3 \text{ deg. rad.}^{-1}$

θ = degrees

The mean port opening

$$P_m = \frac{A(57.3)}{\theta_2 - \theta_1} \text{ inches}$$

The solution is made for the opening period. The closing period is identical and the same mean port opening results.

The mean pressure required to transfer a given charge through the intake port depends upon the mean port area, the time it is open and coefficient of flow. As above stated, the mean area is found by multiplying mean port opening by the circumferential length of the port. The time may be determined from the total crank angle, that the port is open, $2(\theta_2 - \theta_1)$, and the engine speed. The coefficient of flow will depend upon the approach to the port, such as smooth or sharp edges,

or angles, and is in the range of 0.6 to 0.8.

The mean pressure as found by the above was used in determining the volume for the precompression chamber. Inasmuch as assumptions of temperatures and pressures were made, the validity of which the author was not certain, a chamber was designed for varying the precompression volume. This is considered at a later point.

The following calculations were made for a number of port heights in accordance with the foregoing theory:

$$r = 1.625", L = 8.5" \text{ assume } p = 1", m = 3.25 - 1 = 2.25$$

$$k = \frac{r + \frac{r^2}{4L} - m}{57.3} = \frac{1.625 + \frac{2.645}{(4)(8.5)} - 2.25}{57.3} = -0.00954$$

$$\text{at } \theta_1 \text{ } s = m = 3.25 - 1 = 2.25$$

$$2.25 = 1.625 (1 - \cos \theta) + \frac{(1.625)^2}{(4)(8.5)} (1 - \cos 2\theta)$$

$$.5473 = - (1.625) \cos \theta_1 - (0.0777) \cos 2\theta$$

By trial substitutions $\theta = 108^\circ$

Assume $p = 0.75"$. By same method as above, $\theta_1 = 117.5^\circ$

Assume $p = 0.50"$ $\theta_1 = 129^\circ$

Assume $p = 0.25"$ $\theta_1 = 144.5^\circ$

$P = 1"$, $\theta_1 = 108^\circ$

$$\text{Area} = (-0.00954)(72) + (1.625)(.95) + (0.0777)(-.573) =$$

$$-0.687 + 1.545 - 0.0445 = 0.8145" \text{ radius}$$

$$P_m = \frac{(0.8145)(57.3)}{72} = 0.648"$$

TABLE I

Port Opening	θ	$\sin \theta$	$\sin 2\theta$	K	$\theta_1 - \theta_2$	Area	Mean Port Opening
inches	deg.				deg.	"rad.	"
1.00	108	0.950	-0.573	-0.00954	72	0.8145	0.648
0.75	117.5	0.887	-0.819	-0.01391	62.5	0.507	0.465
0.50	129	0.777	-0.978	-0.0182	51	0.2595	0.2915
0.25	144.5	0.581	-0.987	-0.0226	35.5	0.0667	0.1155

In order to strengthen the liner wall, the circumferential width of the port was made that of five axial ports, distributed over 150° . These ports represented about 75% of the total circumferential length, see Figure 6. The net circumferential length was taken as

$$\frac{(.75)(150)(\pi)(3.25)}{360} = 3.2"$$

An engine speed of 1000 r.p.m. was assumed. Atmospheric pressure and a temperature of 150°F. was assumed. Displacement of $3.25" \times 3.25"$ cylinder = $\frac{(\pi)(3.25)^3}{4} = 27.9 \text{ cu.in.}$ Weight of air in this volume

$$w = \frac{(14.4)(14.7)(27.9)}{(53.34)(610)(1728)} = (1.05)(10)^{-3} \text{ pounds}$$

for $p = 1"$

Mean port area = $(0.648)(3.2) = 2.075 \text{ sq.in. or } 0.01441 \text{ sq.ft.}$

Density of charge = $\left(\frac{1728}{27.9}\right)(1.05)(10)^{-3} = 0.065 \text{ pound / cu.ft.}$

Time of port opening = $\frac{(21672)}{360} \times \frac{60}{1000} = 0.024 / \text{second}$

Mean rate of flow at which charge flows into cylinder

$$\begin{aligned} &= (1.05)(10)^{-3} \text{ pound / } 0.024 \text{ second} \\ &= \frac{(1.05)(10)^{-3}}{.024} = 0.0437 \text{ pound / second} \end{aligned}$$

The mean pressure difference may be determined from the formula

$w = 18.3 A_m c \sqrt{h_w d}$ where
 w = mean rate at which charge flows into cylinder
 A_m = mean port area, sq.ft.
 c = coefficient of flow
 h_w = mean pressure difference, inches H₂O
 d = density of charge, pounds / cu.ft.²

For $p = 1"$,

$$0.0437 = (18.3)(1.441)(10)^{-2}(0.6) \sqrt{h_w(0.065)}$$

$$\sqrt{h_w d} = \frac{(0.0437)(10)^2}{(18.3)(1.441)(0.6)} = 0.2762$$

$$h_w = \frac{(0.2762)^2}{0.065} = 1.168 \text{ in. H}_2\text{O} = 0.0421 \text{ pound / sq.in.}$$

By similar calculations

$$\text{For } p = 0.75", A_m = (1.035)(10)^{-2} \text{ sq.ft.}$$

$$t = 0.0282 \text{ sec.}$$

$$\text{mean rate of flow} = 0.0504 \text{ pound / sec.}$$

$$\text{and } h_w = 0.1089 \text{ pound / sq.in.}$$

$$\text{For } p = 0.5", A_m = (0.648)(10)^{-2} \text{ sq.ft.}$$

$$t = 0.017 \text{ sec.}$$

$$\text{mean rate of flow} = 0.0618 \text{ pound / sec.}$$

$$\text{and } h_w = 0.42 \text{ pound / sq.in.}$$

$$\text{For } p = 0.375", A_m = (0.4395)(10)^{-2} \text{ sq.ft.}$$

$$t = 0.0145 \text{ sec.}$$

$$\text{mean rate of flow} = 0.0724 \text{ pound / sec.}$$

$$h_w = 1.25 \text{ pound / sq.in.}$$

$$\text{For } p = 0.25", A_m = (0.256)(10)^{-2} \text{ sq.ft.}$$

$$t = 0.0118 \text{ sec.}$$

$$\text{mean rate of flow} = 0.089 \text{ pound / sec.}$$

$$\text{and } h_w = 5.59 \text{ pound / sq.in.}$$

Calculations were made for 1200 r.p.m., which resulted in the following values of mean pressure difference for the port heights assumed:

$$P = 1", h_w = 0.0622 \text{ pound / sq.in.}$$

$$P = 0.75", h_w = 0.175 \text{ pound / sq.in.}$$

$$P = 0.50", h_w = 0.605 \text{ pound / sq.in.}$$

$$P = 0.375", h_w = 1.80 \text{ pounds / sq.in.}$$

$$P = 0.25", h_w = 8.00 \text{ pounds / sq.in.}$$

The intake was designed with an approach inclined at the same pitch as the top of the piston head to direct the incoming mixture upward and increase the efficiency of scavenging. This method is suggested by Judge in reference to the design of Diesel engines employing the two-stroke cycle.

By-pass calculations: Figure 7 presents a diagrammatic representation of the volumes used in the calculations made for the by-pass problem. The volumes indicated represent:

V_D = displacement volume inside piston

V_H = volume under dome of inside piston head

V_A = clearance volume inside piston

V_P = volume of three ports between inside piston volumes and by-pass chamber

V_C = pre-compression space volume

V_S = clearance volume in by-pass adjustment cylinder

V_V = variable (displacement) volume in by-pass adjustment cylinder

$V_{BP} = V_S + V_V + V_C$ = total volume in by-pass

D = diameter of inside piston chamber

$$= 3.25 - (2)(0.1875) = 2.975"$$

$$V_D = \frac{(2.975)^2}{4} (3.25) = 21.4 \text{ cu.in.}$$

V_H = 0.685 cu.in. (from estimated dimensions available)

$$V_A = \frac{(2.975)^2}{4} (0.25) = 1.64 \text{ cu.in.}$$

V_P = (arc length)(wall thickness)(port heights)

$$= (3.2)\left(\frac{1}{8} + \frac{3}{16}\right)\left(\frac{5}{8} + \frac{7}{16} + \frac{7}{16}\right) = 0.60 \text{ cu.in.}$$

V_C = (2.5)(4.5)(1.25) = 14.05 (estimated dimensions available)

Assumption I

$$P_1 = 14 \text{ pounds / sq.in. Absolute}$$

$$P_2 - P_1 = 2.5 \text{ pounds / sq.in.}$$

$$P_2 = 16.5 \text{ pounds / sq.in. Absolute}$$

$$k = 1.33$$

$$V_1 = 21.4 + V_2 \text{ cu.in.}$$

$$\frac{V_1}{V_2} = \frac{(P_2)^{\frac{1}{k}}}{(P_1)^{\frac{1}{k}}}$$

$$\frac{21.4 + V_2}{V_2} = \frac{(16.5)^{\frac{1}{1.33}}}{(14)^{\frac{1}{1.33}}} = 1.24$$

$$V_2 = \frac{21.4}{0.24} = 89 \text{ cu.in.}$$

$$V_1 = 89 + 21.4 = 110.4 \text{ cu.in.}$$

Assumption II

$$P_1 = 14 \text{ pounds / sq.in. Absolute}$$

$$P_2 - P_1 = 11 \text{ pounds / sq.in.}$$

$$P_2 = 25 \text{ pounds / sq.in. Absolute}$$

$$\frac{21.4 + V_2}{V_2} = \left(\frac{25}{14}\right)^{\frac{1}{1.33}} = 1.56$$

$$V_2 = \frac{21.4}{0.56} = 38.2 \text{ cu.in.}$$

$$V_1 = 38.2 + 21.4 = 59.6 \text{ cu.in.}$$

$$V_H + V_A + V_P + V_{BP} = V_2$$

$$V_{BP} = V_2 - V_H - V_A - V_P$$

For assumption I,

$$V_{BP} = 89 - 0.685 - 1.64 - 0.60 = 86.075 \text{ cu.in.}$$

For assumption II,

$$V_{BP} = 38.2 - 0.685 - 1.64 - 0.60 = 35.275 \text{ cu.in.}$$

For assumption I,

$$V_S + V_V = 82.075 - 14.05 = 68.025 \text{ cu.in.}$$

For assumption II,

$$V_S = V_V = 38.2 - 14.05 = 24.15 \text{ cu.in.}$$

Then for $V_V = 0$. $V_S = 24.15 \text{ cu.in.}$

$$A_S = (4.5)(3) = 13.5 \text{ sq.in. (From work sheet)}$$

$$L_S = \frac{24.15}{13.5} = 1.79 \text{ in. depth of by-pass adjustment cylinder flange}$$

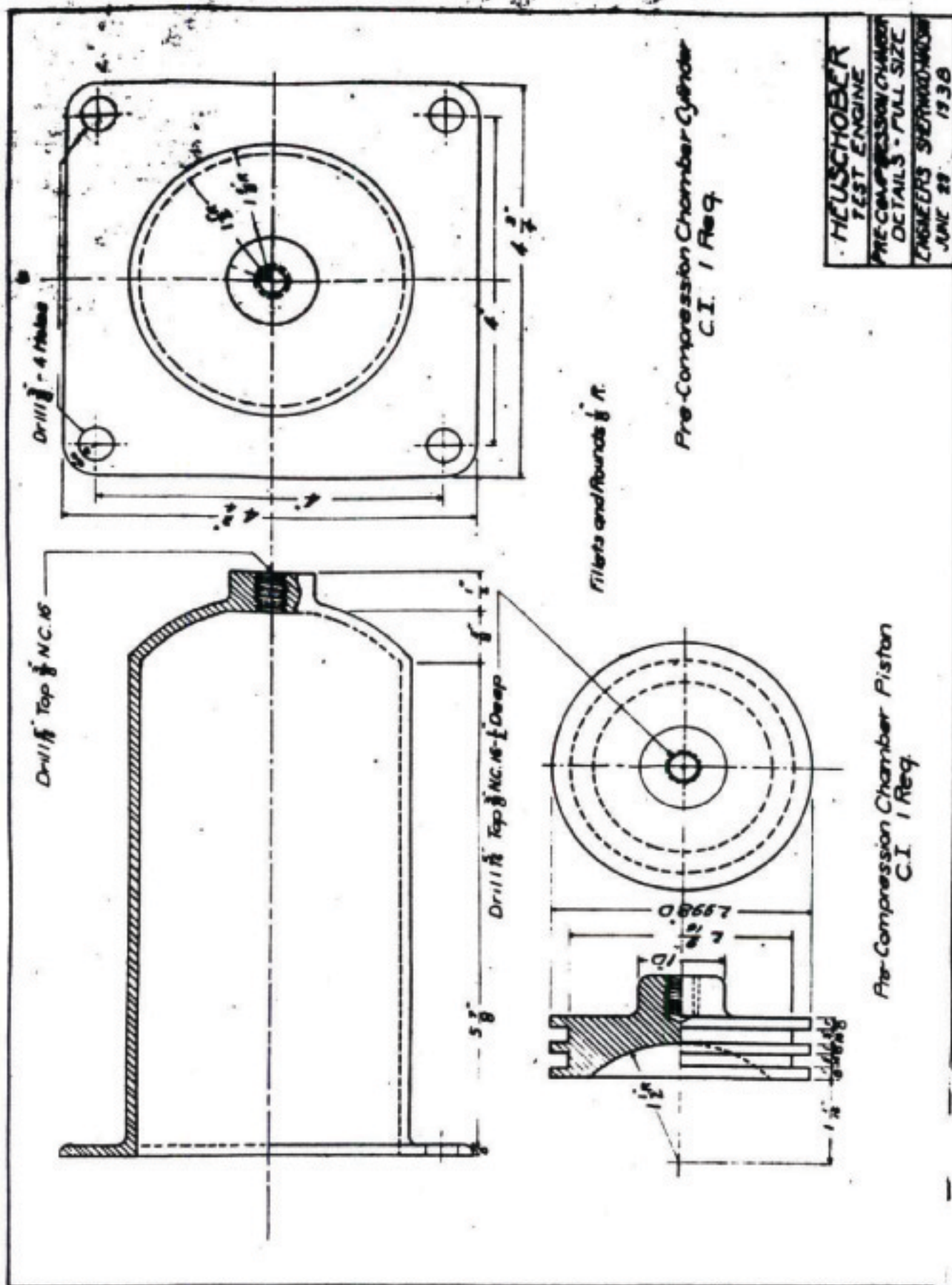
$V_V = V_{BP \text{ I}} - V_{BP \text{ II}} = 68.025 - 24.15 = 43.875 \text{ cu.in. adjustment}$
in by-pass adjustment cylinder.

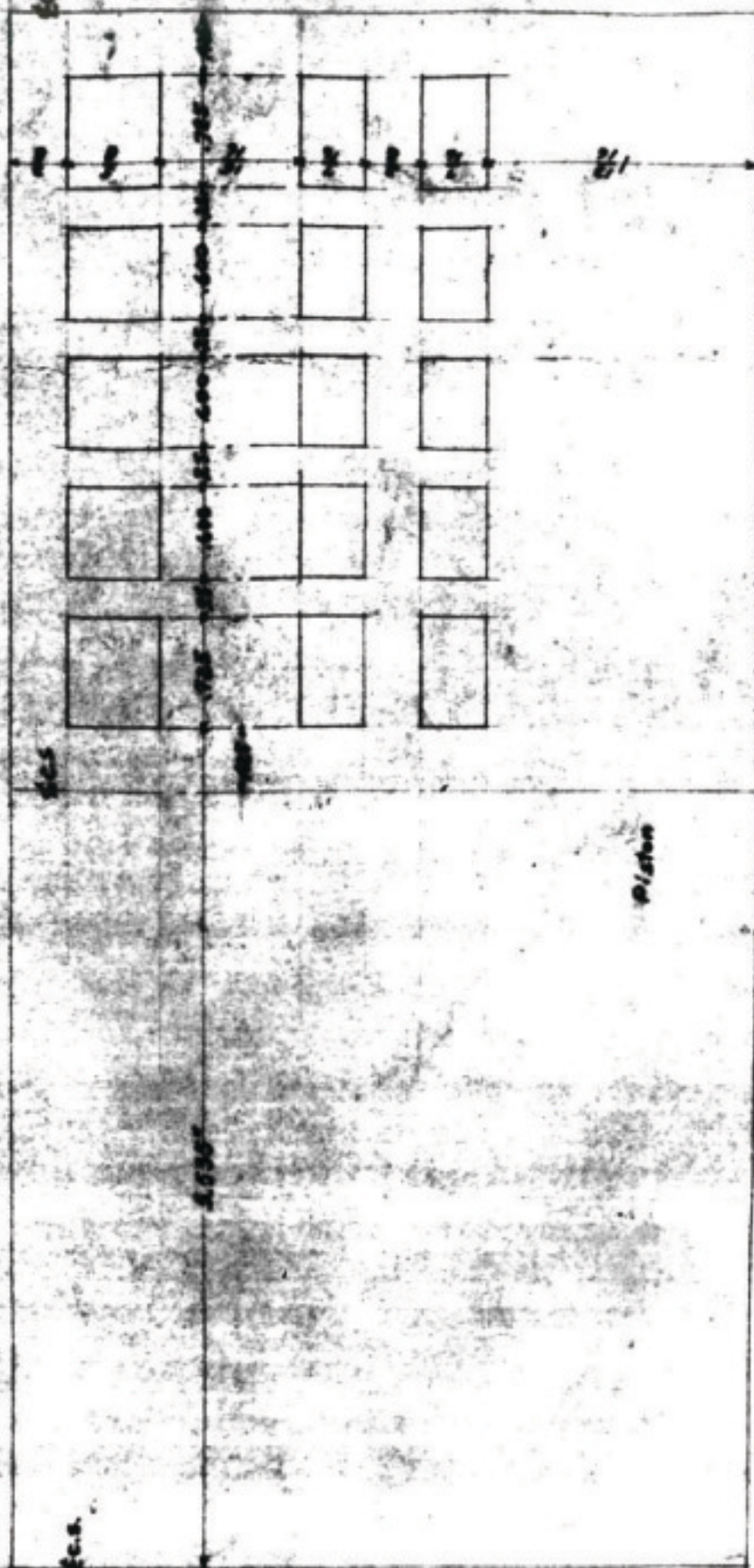
$$L_V = \frac{V_V}{A_V} = \frac{(43.875)(4)}{(3)^2} = 6.22 \text{ in.}$$

L_V = length of piston travel in by-pass adjustment cylinder
to give limits assumed in Assumption I and II. See photostat of blue prints
of by-pass adjustment cylinder, Page . The dimensions used varied
somewhat from the first calculated values as given by these sample
calculations.

The design of the port 14 in the piston and 8 in the cylinder
between the inner piston chamber and the by-pass chamber resolved itself
into a number of considerations: (a) the weakening of the piston and
the cylinder by the port area, (b) the matter of finding a maximum
average effective port area, (c) finding a design which would cut down
wiredrawing.

Consideration (a) was solved by making the total port area into
a number of smaller ports with the metal between the smaller ports acting
as beams. This is shown in a development of the piston wall, Page ,
which was constructed for the mechanic's use in center punching the





Template for Ports in Piston Sleeve

cylinder for drilling and cutting out the ports.

Consideration (b) was solved by assuming a number of variations of port sizes and calculating for each combination the port opening areas while the piston moved on the suction stroke of inner chamber piston. These areas were plotted against the crank angle and the mean ordinates determined. The maximum average port opening determined the dimensions used in the test engine design.

Consideration (c) was solved by specifying the removal of burrs and smoothing of sharp edges. Careful inspections of this were made.

The design of the exhaust port 9 in the cylinder wall was solved by selecting a port height such that the port would open by action of the downward motion of the piston slightly before the intake port 8 was uncovered. This allowed the pressure to lower in the combustion chamber and started the exhaust gases in motion before the air-fuel mixture entered. The scavenging probably was completed before the exhaust port was closed. However, it was thought that the preventing of flowing exhaust gases into the by-pass chamber with possible backfiring was more important than the possible inefficiency from the loss of air-fuel mixture through the exhaust after scavenging. No complicated design on exhaust ports was made: An exhaust pipe was specified for carrying the blue exhaust gases a short distance away from the engine.

The combustion space 16 was dependent upon (a) the shape of the cylinder head, (b) the shape of the piston head.

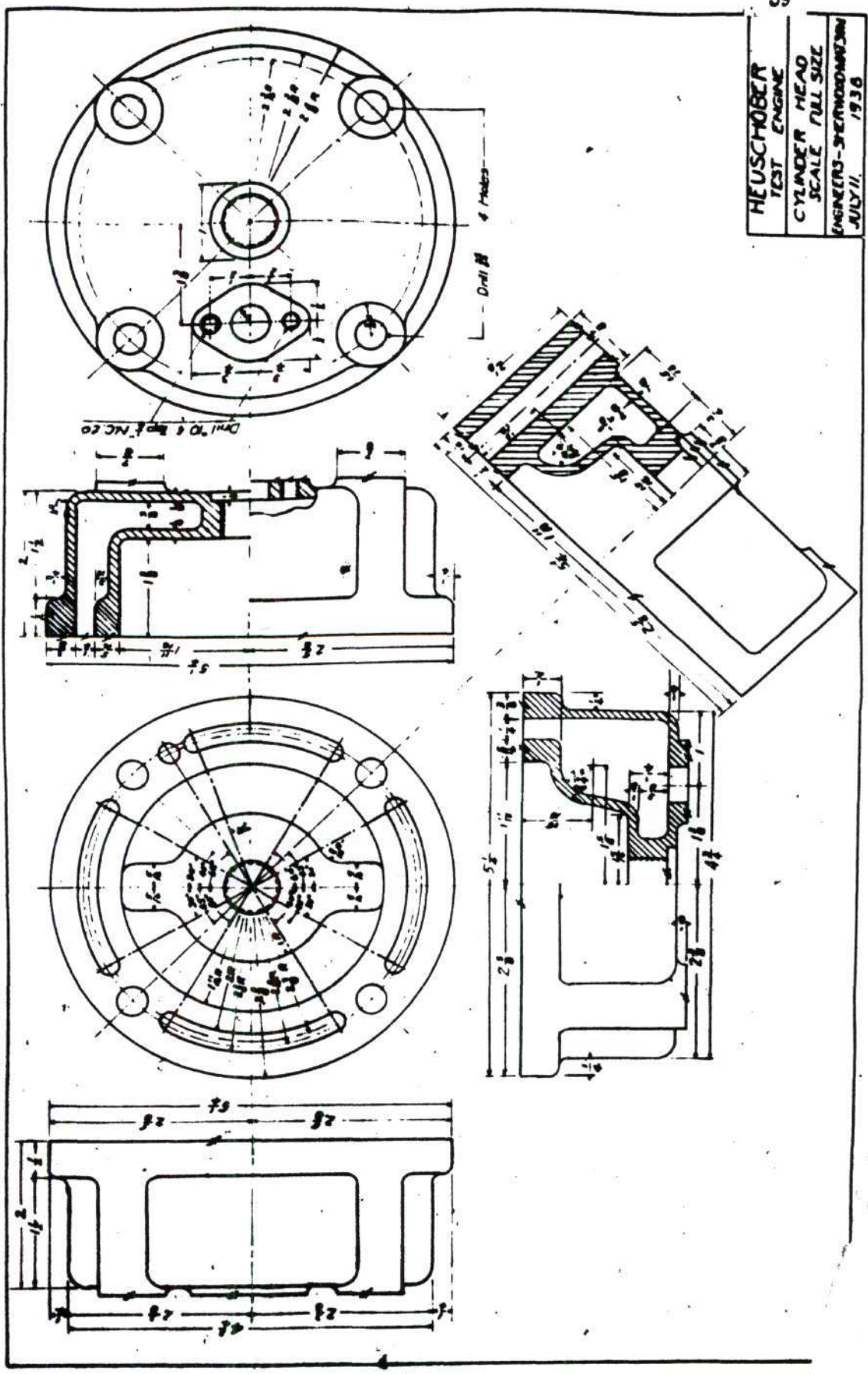
Since it had been decided to use water cooling in the test engine instead of air cooling as the inventor had done with his model

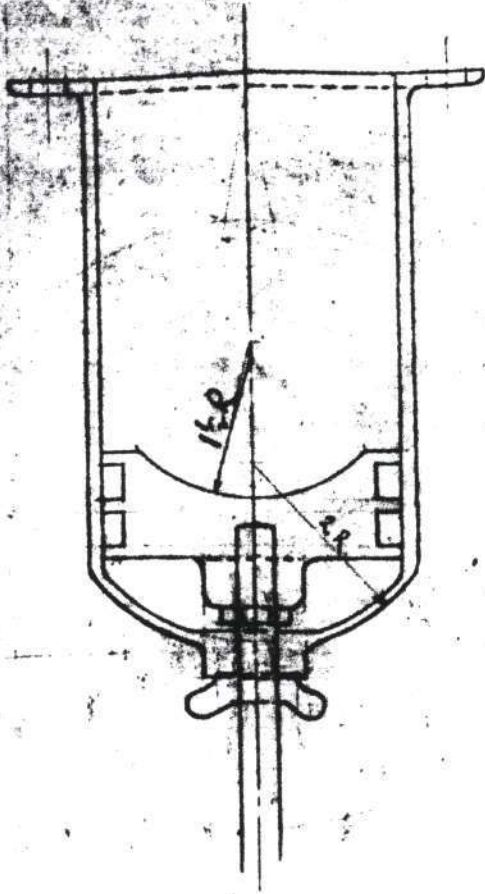
engine, the cylinder head was laid out as shown in photostat copy of the cylinder head, Page 39. No particular design formulae were used. The purpose of the engine was to test the inventor's principle, and there was not sufficient time to experiment or to even investigate the literature on this subject.

The piston head was designed as shown in the photostat copy of the piston head, Page 42. The steep curvature of the lip toward intake tended to throw the incoming air-fuel mixture upward and to blow combustion gases downward and out the exhaust over the more gradual sloped portion of the head. This is a common form of piston head and is used in many small engines.

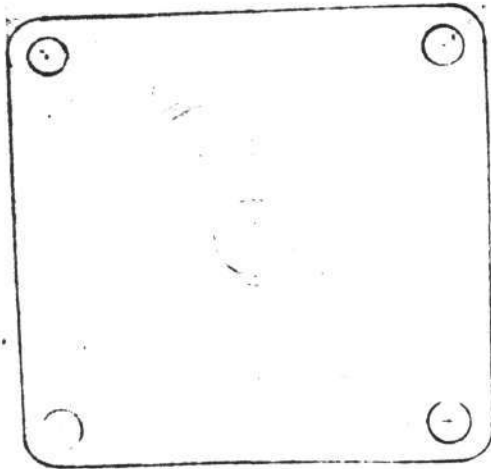
The model engine used only two posts or columns 16 to position the rigid piston 15 inside the engine piston 12. The inventor had some difficulty in avoiding interference with the connecting rod. Two point suspension is not a sound method. Three point suspension is ideal, but space conditions would not permit. The author made a "rubbing" of the top of the engine base, and plotted the path of the connecting rod. He designed a pair of plates which were placed in the manner of shims to which four bars were attached by lock nuts after screwing the upper end into tapped holes in the rigid piston 15. This method was used likewise in the commercial engine by Mr. Shepherd. The photostat of the work sheet of this "rubbing" is shown on Page 42.

Due to the unorthodox nature of the Heuschober principle, the rigid piston had to be placed inside the piston sleeve. The wrist pin bosses in the elongated skirt interfered with assembly at one end and a solid head at the other. It was evident that the wrist pin bosses could

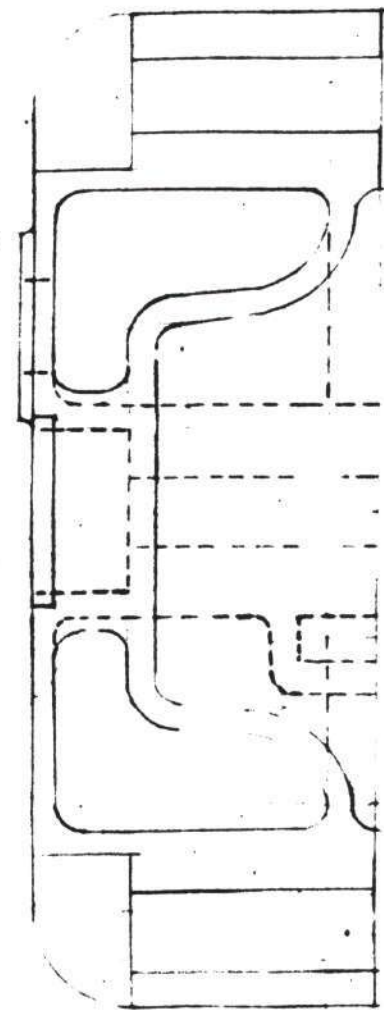




*Variable By-pass Cylinder
(Working Sketch only.)*

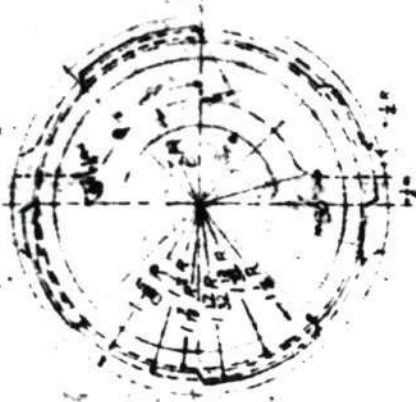
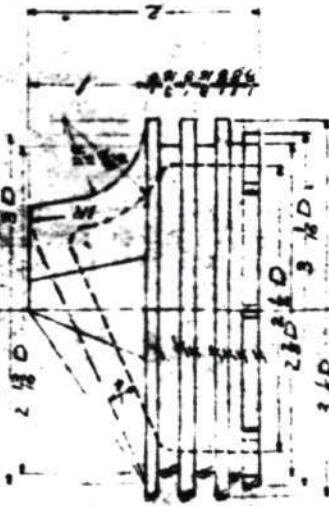


Sample Work sheets

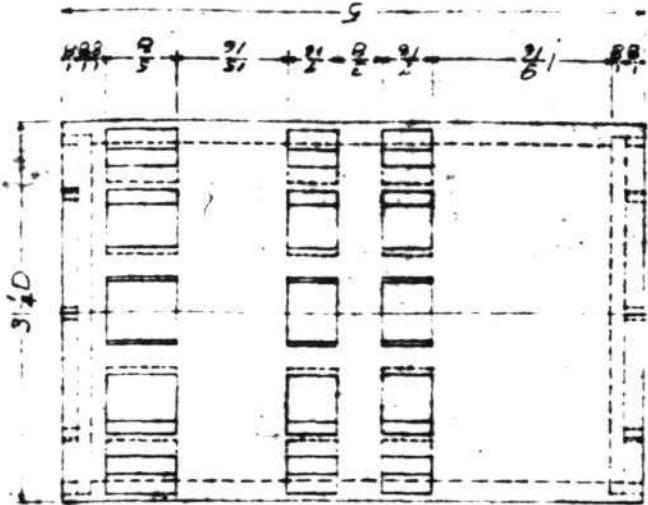


*CYLINDER HEAD
WORK SHEET*

Piston Head



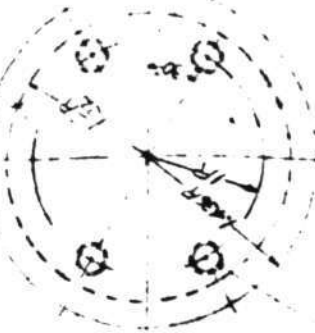
Piston Sleeve



Piston Base



Stationary Diagram

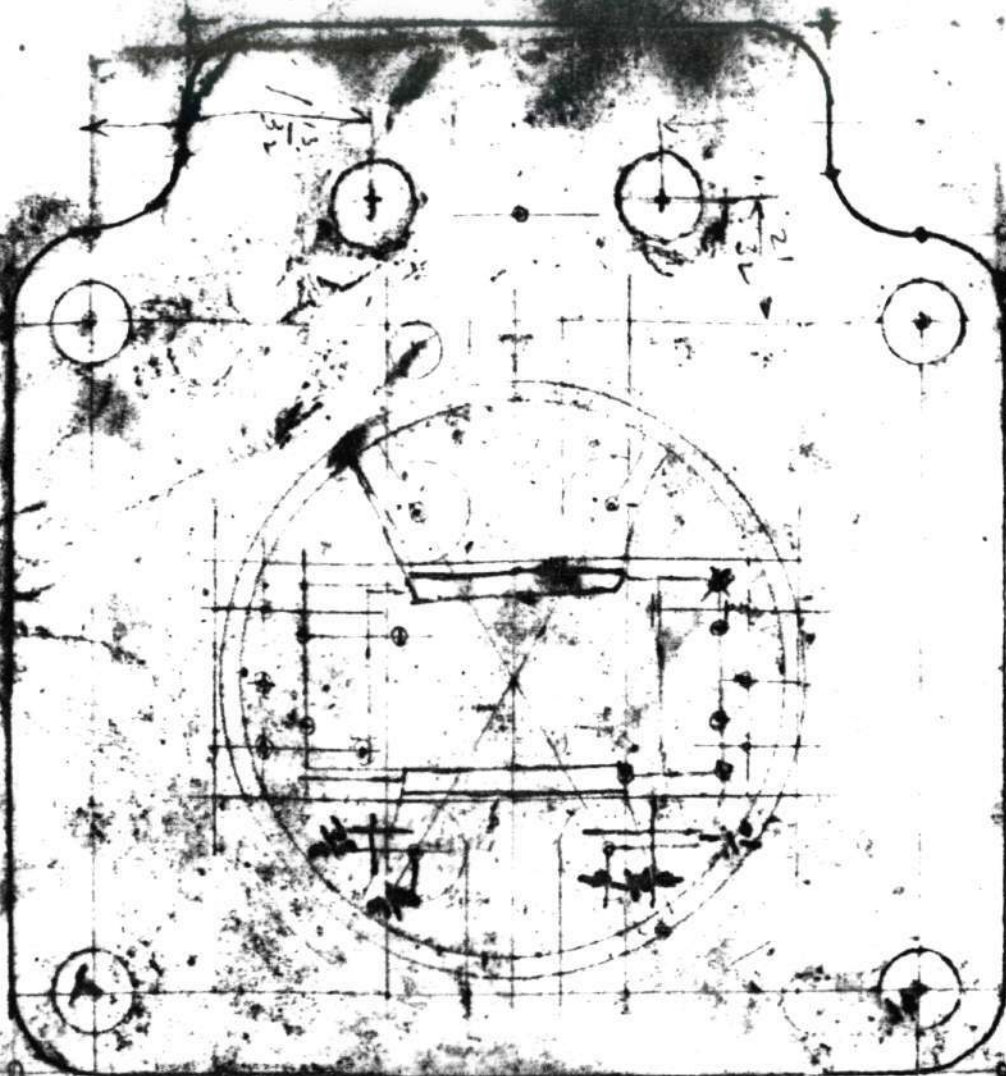


Drill and Ream 1/4" SAE 1-10
HEUSCHUBER
TEST ENGINE
PISTON DETAILS
FULL SCALE

41
JUN 1932

C.I. 1 Req

C.A.I. 1 Req



Work Sheet Rubbing of base for layout of
Stationary Diaphragm Base Plate to hold spacer
rods to position stationary piston.
(Used to lay out Plate)

not be constructed with a thickness as small as that of the piston sleeve. The combustion and inertia forces would cause failure by tearing out the skirt. The walls of the piston sleeve could not be made thicker (a) without reducing the volume of the inside chamber, (b) without increasing the mass of the piston (already greater than an orthodox piston because of the elongated skirt).

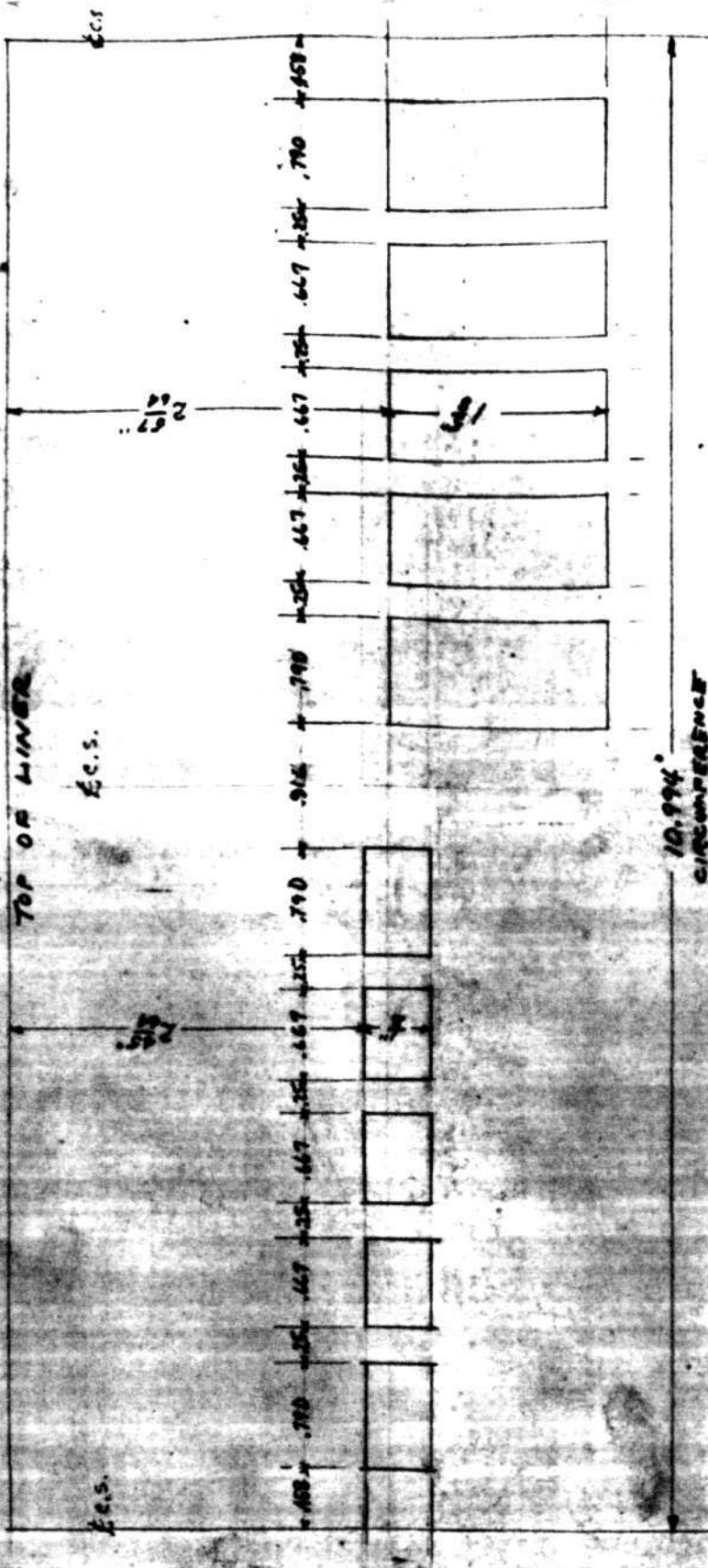
The Heuschober model engine had a head machined as a separate part to fit on the sleeve and pinned radially from the sides. All stresses were carried by the pins.

This general method with slight changes as shown on photostat of the blue print, Page 41, was used on the test engine. The sleeve and the head were each slotted so that the head was pressed down on the sleeve and turned through an angle of 45 into a recessed groove. Coaxial pins were driven to hold the head and sleeve rigidly keyed together. The pins took only initial low stresses applied during assembly. The stationary diaphragm was inserted with oil rings in place before the head was keyed to the sleeve.

The piston base was assembled to the lower end of the piston sleeve in a similar manner.

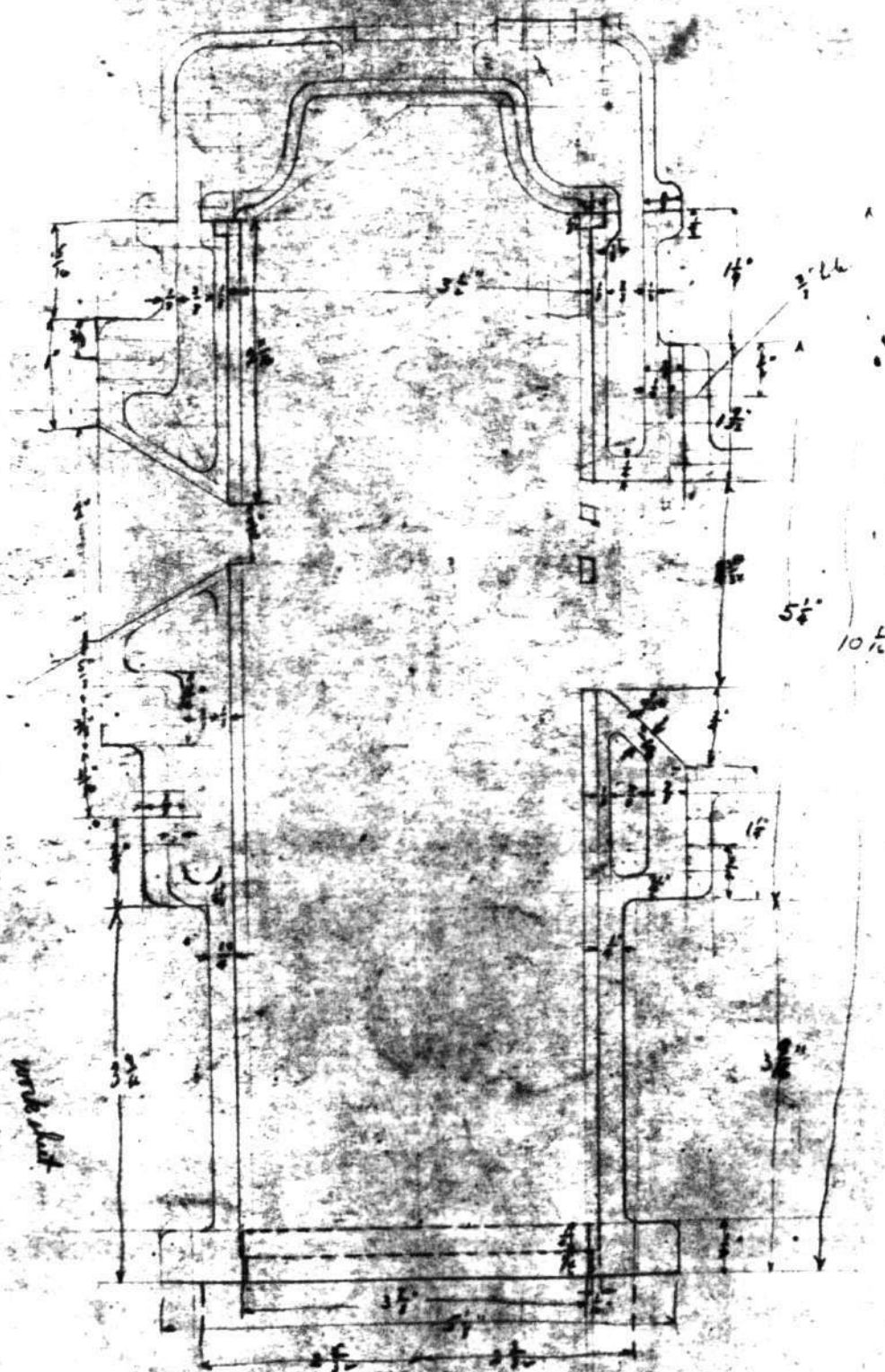
The piston sleeve was more easily fabricated separate from both head and base. The ports were cut as easily as holes in any cylindrical barrel. A photostat of the templet for cutting is shown on Page 45.

The repair in three days of the failure mentioned in the letter from Lion Oil Company, photostat copy on Page 78, was possible because of a similar method of assembling the head to the piston sleeve, as

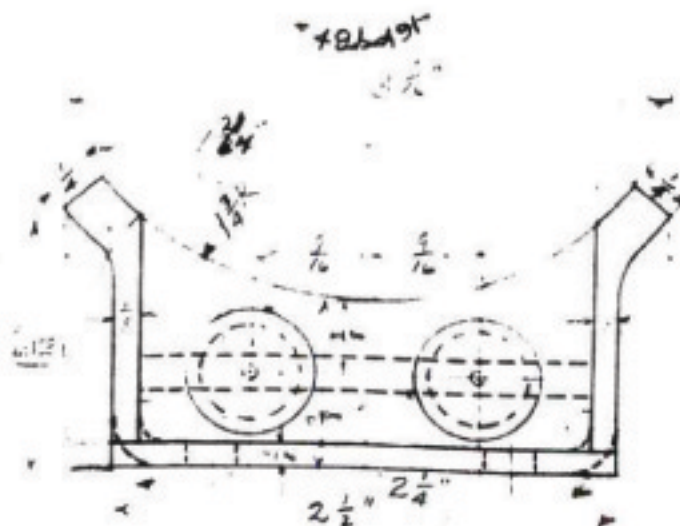


Template for Ports in Cylinder Liner

shown on photostat of the elevation of the Lufkin engine, Page 72. The pins were removed by drilling with an undersized drill and by picking out the remaining shell of the pin.



Copyright © 1964 by the United States Government



1 1/2"

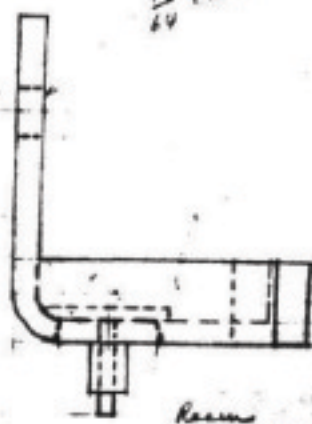
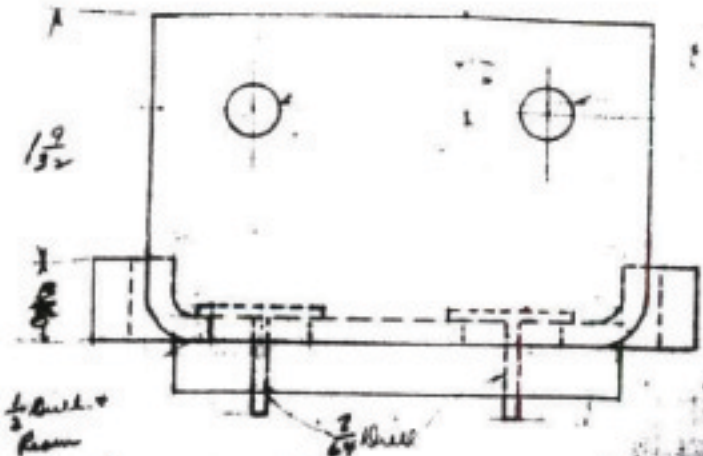
Wrong Dimension

Sherwood check.

RMM

Auxiliary Inlet Valve Bonnet

Work Sheet



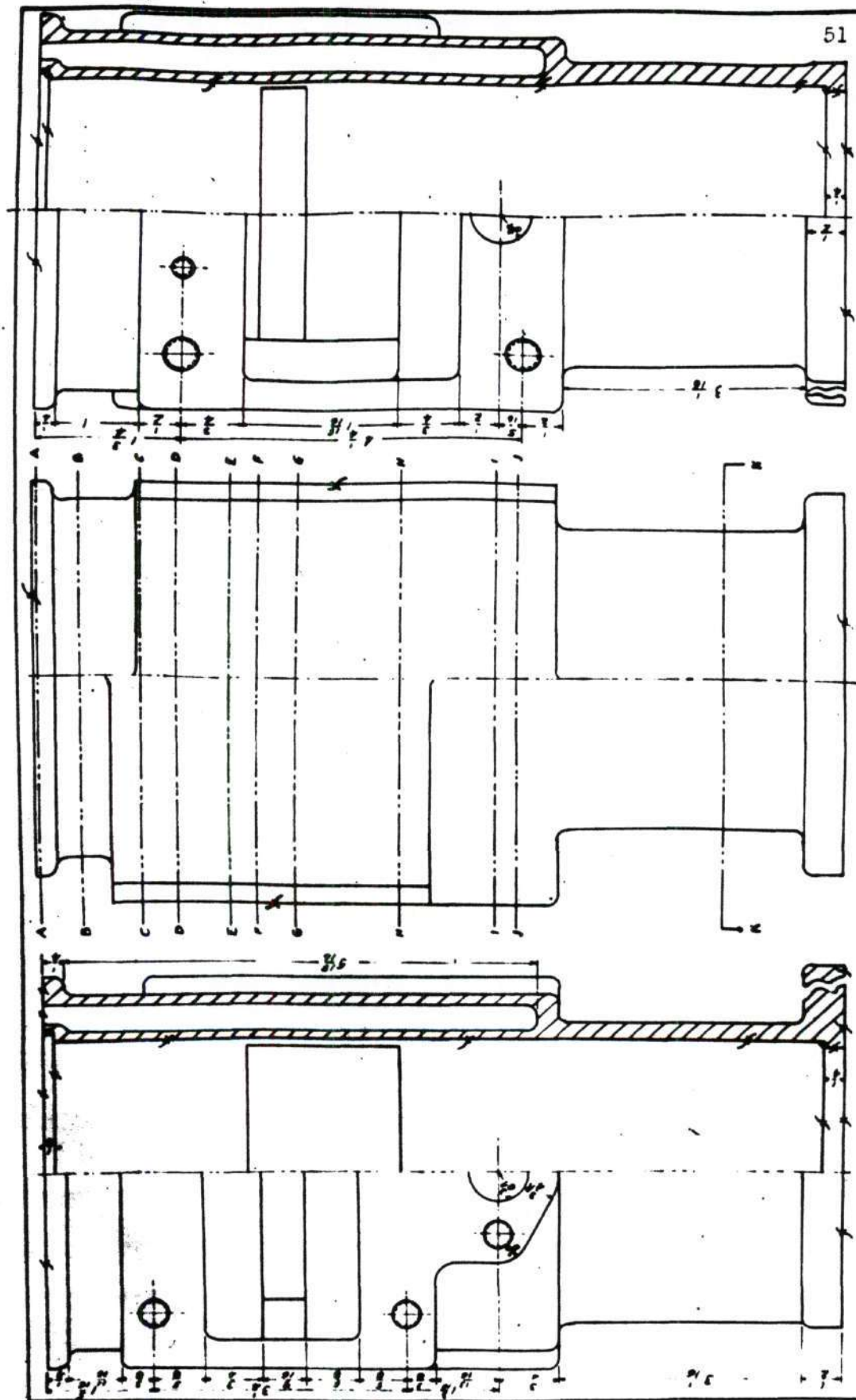
Work Sheet. Auxiliary Inlet Valve Bonnet.

FABRICATION PROBLEMS

Mr. Heuschober arranged for a local pattern maker to make all patterns for the block, heads (cylinder and piston), piston sleeve, exhaust plate, pre-compression chamber coupling, cylinder, piston, cylinder liner, stationary piston, auxiliary intake bonnet, and carburetor connection. The pattern for the block presented the only real difficulty. This problem is discussed in a later paragraph.

The foundry which Mr. Heuschober first contacted to make the casting delayed so long that a second and smaller foundry was employed. The principal difficulties resulted from the work of a moulder of slight experience. The cores for the interior space in which the liner was to be placed were not rigidly positioned. These cores drifted during pouring and the walls between the water jacket and the liner cavity tapered from the correct wall thickness at the top to wall thicknesses at the bottom of $1/16$ " on one side and $3/16$ " on the other. The moulder placed an extra core through the wall of the water jacket to fix the offending core. This left a gaping hole which rendered the second casting useless. These difficulties occurred while Mr. Sherwood and the author both were absent. Upon their return, they showed the moulder how to anchor the cores into position with wires and nails. These were strong enough for that purpose yet small enough to offer little obstruction to the flow of water through the jacket.

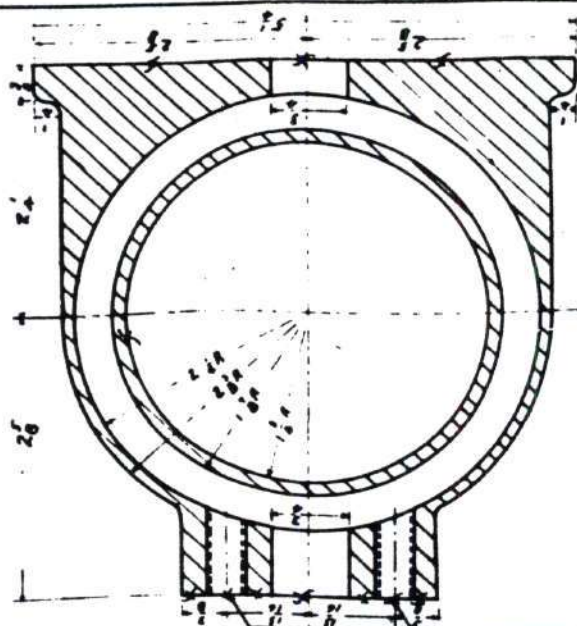
The machinist who had worked with Mr. Heuschober during his "trial and error" effort was employed to do all machine work. The principal difficulty in his work was the result of using national fine



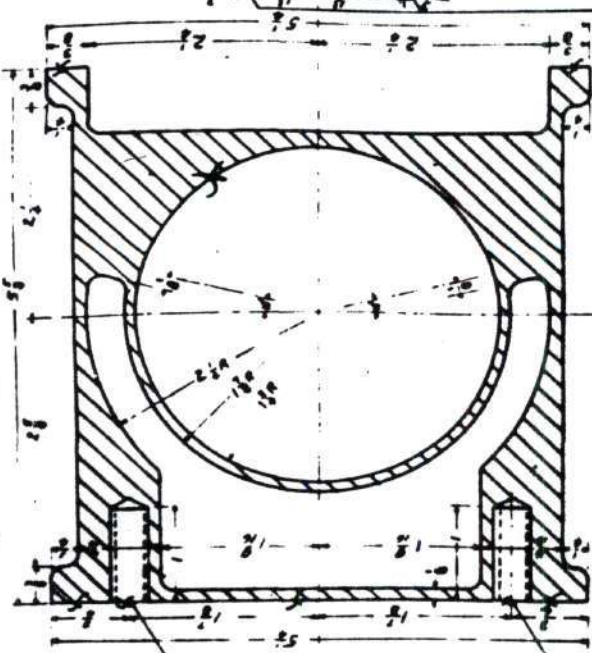
C. I. 1 Req.
Flights and Rounds 8

Drill 18 Exp 1 MC 18 - 4 Holes

①

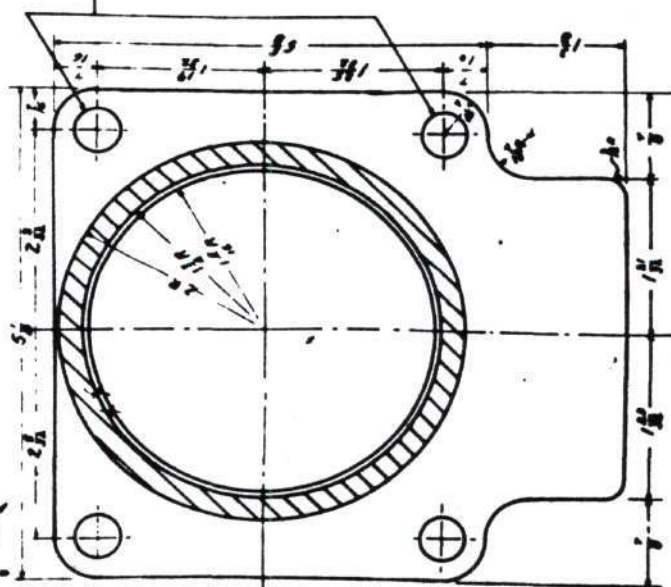


②



Drill 1/2" N.C. 16

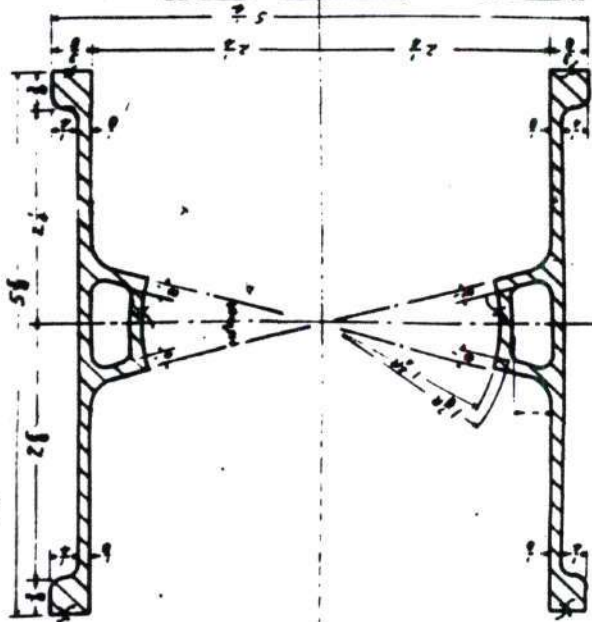
③



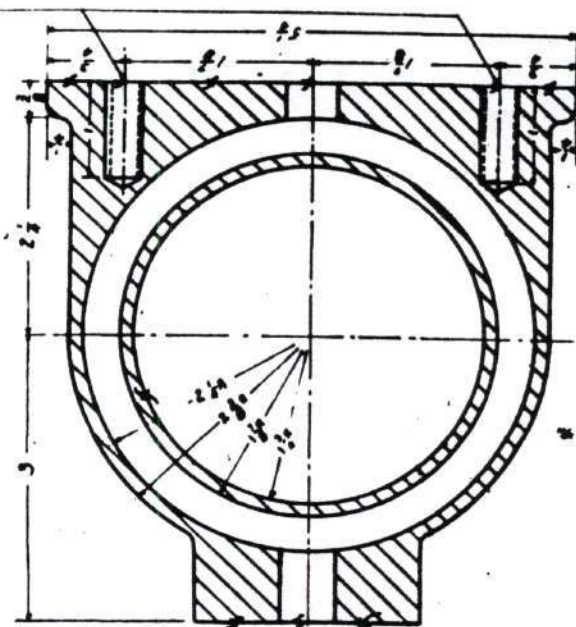
Drill 1/2" 4 Hole

Fillets and Rounds 1/8"

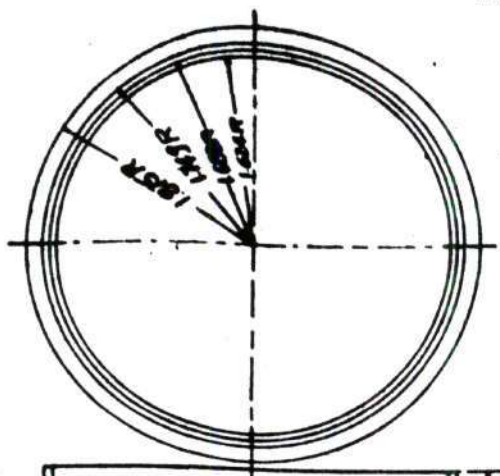
④



⑤

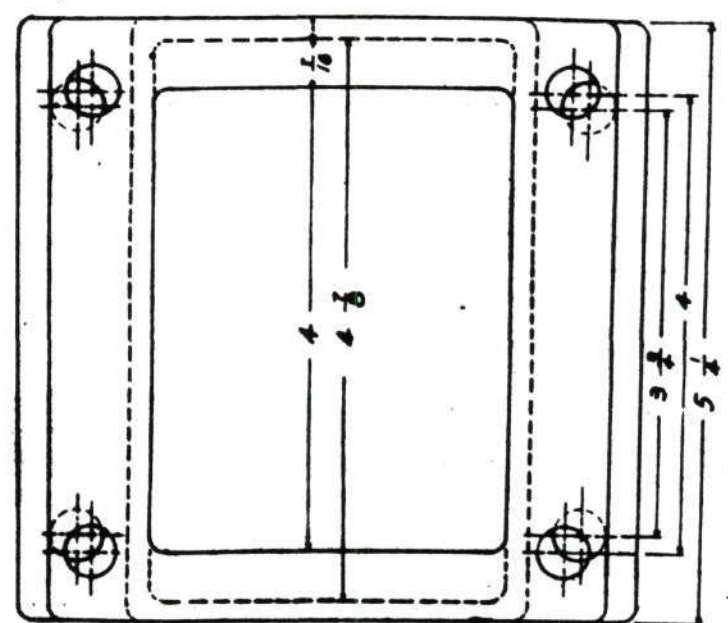
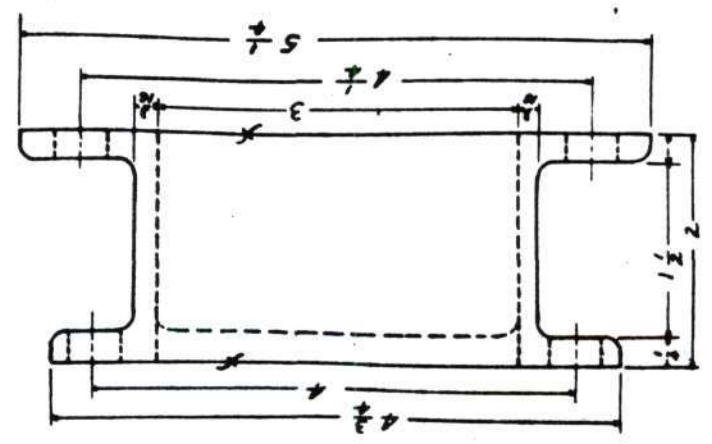


HEUSCHLOBER	TEST ENGINE	PRE-COMPRESSION CHAMBER	COUPLING - CYLINDER UNDER	ENGINEERS-MATSON-SHEARER
			SOLE FULL SIZE	JULY 5 1938



Pilots and Rounds $\frac{1}{2}$

Drill All Holes $\frac{1}{2}$



Cylinder
Liner

**Pre-Compression
Chamber Coupling**

taps for tapping holes in the aluminum casting of the block. These taps have threads of depth too small to allow proper tightening and to stand constant insertion and removal during adjustment and test operations. The remedy which was used, drilling the holes larger and tapping with national coarse taps, is not to be considered as a recommended practice. The early troubles in foundry and machine shop impressed upon the engineers the need for constant supervision and inspection when poorly trained workmen were employed. It became evident that the use of cheap labor is at times poor economy.

ASSEMBLY PROBLEMS

The assembly of the test engine was carried on simultaneously with some of the later inspection work. There were a number of points where some difficulties in assembly were anticipated. Fortunately, the checking of dimensions during design and the careful recheck of certain layouts, such as those depending upon "rubbings" of the standard parts (discussed previously) precluded serious difficulty. It had been extremely difficult to predict the expansion of parts in high temperature localities, but the attempts which had been made to allow for this proved to be so close that fits were corrected by additional grinding and lapping. The greatest difficulty occurred in the overheating which came from the use of the lubrication system of the standard engine crank case. This system caused trouble throughout the first part of the test period. The extra length of the piston skirt presented a greater surface to be oiled than the pump capacity provided. In the later part of the test period, an electrically driven auxiliary oil pump was provided. Since the Heuschober principle to be tested had no relation to the oil pump, this added accessory presented no effect upon the validity of the test. Consideration was given to a method of introducing oil through small holes to be drilled into the side of the walls of the block below the level of the exhaust port but this was not done. Piston rings were used both on the piston proper and on the stationary diaphragm. A later patent claim of the inventor provided for passing the lubricant to the rings in the stationary diaphragm through one of the stud bolts used for positioning the diaphragm, a threaded tube being employed.

TEST WORK AND REPORTS

At the end of the summer of 1938, both Mr. Sherwood and the author returned to duties at Southern Methodist University. The assembly of the test engine had been completed and the engine had been run in for short periods at low speeds. However, no actual tests had been made.

The engine was moved from Fort Worth to the laboratory of the Department of Mechanical Engineering of Southern Methodist University in Dallas in order to simplify the testing program. Mr. Sherwood was retained by Mr. Heuschober for doing the actual testing work. Through the courtesy of Mr. Stanley Patterson, Superintendent of the Plant Department and Instructor in Shop Practice in the Department of Mechanical Engineering, temporary connections to the gas lines were provided for testing with natural gas in addition to gasoline.

The author served in advisory capacity to the routine testing and was present and assisted during any test which was to be reported to the Heuschober Engineering Corporation. Written reports were submitted by him after each test. Statements were made concerning progress of the tests at regular and called meetings of the board of directors and of the stockholders.

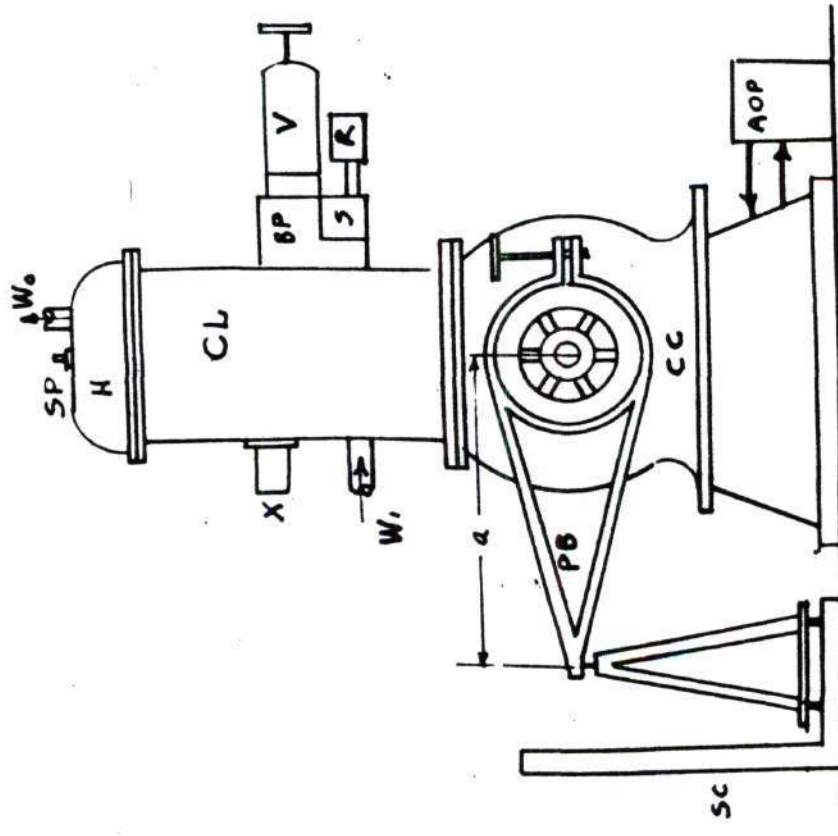
It was originally contemplated that an elaborate study be made of results from the use of a number of cylinder liners varying the port heights throughout a considerable range and the speed throughout a range from 200 to 2200 r.p.m. However, the board of directors decided after reviewing a number of the author's reports, which had indicated optimistic

results, that the Heuschober principles had been sufficiently established and that further testing of the test engine would be unnecessary. Their pleasure was that design work should be started as soon as possible upon a size that could be offered for service in the oil pumping field. The author suggested that the first design be another single cylinder engine which could develop approximately 25 horsepower at a speed in the range of 400 to 600 r.p.m., and that a multi-cylinder engine be delayed until test data be compiled on the larger size.

The author was too involved in administrative duties as well as class instruction at Southern Methodist University to assume an active part in this next step. From time to time the author was called upon for consultation. Mr. Sherwood took over the design of the larger test engine, which became the basis of the commercial engine discussed in a later section.

Figure 9, Page 59, shows the arrangement of apparatus used in the laboratory tests during the fall of 1938. The engine was allowed a further running in period during which unofficial observations were made of its performance. The lubrication difficulties, previously noted, made their appearance. After numerous attempts were made to make the original oil pump deliver sufficient oil at great enough pressure to supply lubrication to the upper rings of the long skirted piston, the auxiliary oil pump shown diagrammatically on Figure 9 was installed. Holes were drilled in the piston at points which did not interfere with porting but through which oil could pass to the upper rings during the slow speed portion of the stroke near bottom dead center. Only two sets of cylinder liners were used before the tests were stopped. The by-pass

a - BRAKE ARM
 AOP - AUXILIARY OIL PUMP
 BP - BY-PASS CHAMBER
 CC - CRANK CASE
 CL - CYLINDER BLOCK
 H - CYLINDER HEAD
 R - CARBURETOR
 S - CHECK VALVE ASSEMBLY
 SC - SCALES
 SP - SPARK PLUG
 V - VARIABLE VOLUME
 W_i - COOLING WATER IN
 W_o - COOLING WATER OUT
 X - EXHAUST PIPE



ARRANGEMENT FOR TEST
 HEUSCHÖBER TEST ENGINE

FIGURE 9

September 20, 1930.

Heuschober Engineering Corporation,
Fort Worth, Texas.

Attention: Mr. E. E. Heuschober, President.

Dear Sir,

I would respectfully submit the following report on results of horsepower tests made on (a) the Heuschober Model two-stroke-cycle Internal Combustion Engine built by you and embodying principles which you have patented, and on (b) the Heuschober Test two-stroke-cycle Internal Combustion Engine which has been built after the design made by Mr. Noble P. Sherwood, Instructor in Mechanical Engineering, School of Engineering, Southern Methodist University, and the writer, Prof. Ray M. Matson, Head of the Department of Mechanical Engineering, School of Engineering, Southern Methodist University, and embodying the same patented principles but designed with reference to the laws of thermodynamics, fluid dynamics and machine design.

The Heuschober Model Engine is two-stroke-cycle, single cylinder, air-cooled, with 3 1/4" stroke and 3 1/4" bore and developed 1.4 horsepower at 1000 r.p.m. This test was of short duration due to lack of proper balance, which caused excessive vibration, and lack of sufficient lubrication and use of air cooling which caused excessive heating.

The Heuschober Test engine is also two-stroke-cycle, single cylinder, water-cooled with 3 1/4" bore and 3 1/4" stroke, with a number of specially designed devices for varying port areas and chamber volumes. Three preliminary tests upon this Test Engine showed a developed horsepower of 3.06 at 1000 r.p.m. Cooling water: in, 80°F; out, 155°F. Fuel for each test was low grade gasoline.

The engineers are pleased with the above results which show an increased output of 1.66 horsepower for the Heuschober Test Engine over the Heuschober Model Engine, in other words an increase of 118.56%.

The engineers see no reason why a commercial engine should not be developed if sufficient capital be provided to finance more complete tests upon the Test Engine and the design of a larger multicylinder engine based upon the results of these tests. Such an engine, we believe, would compare favorably with engines now on the market and in service and would be attractive due to the same simplicity of design which has been applied to the Test Engine, and the fact that crank case compression is not used permitting positive lubrication to all bearings and pistons. This eliminates the current practice of mixing lubricating oil with the fuel.

Very truly yours,

Ray M. Matson, Head,
Department of Mechanical Engineering,
School of Engineering,
Southern Methodist University.

November 15, 1938.

Mr. E. E. Heuschouer, President,
Heuschouer Engineering Corporation,
2845 Eighth Avenue,
Fort Worth, Texas.

Dear Sir,

I am enclosing a chart showing results of the Preliminary Tests which were made yesterday on the Heuschouer Test Engine, using Humble "Regular" Gasoline.

You will note that the Horse Power has been corrected to S. A. E. Standard Conditions. I wish to call your attention to the smooth torque curve particularly since these tests were made at speeds in excess of the design conditions.

I am pleased with the results in view of the fact that the engine was designed to investigate the possibility of the Heuschouer Principles and has the possibility of much further refinement.

I would suggest that there is a chance of improvement in performance with a larger size and with either three or four cylinders. I also believe that the principle can be applied to an application to the Diesel Cycle with four stroke principle.

Hoping that the enclosed will be of interest to you, I am,

Very truly yours,

W. J. Mendenhall, M.S.,
Department of Mechanical Engineering,
Southern Methodist University,
Dallas, Texas.

WJM/m.

HEUSCHOBERT TEST ENGINE

3 1/4" x 3 1/4" TWO STROKE CYCLE.

62

NOV. 14, '38.

N. P. SHERWOOD
RAY M. MATS

ROOM TEMP 82°F BAR. PRESS 29.38" Hg. FUEL: HUMBLE REGULAR
BRAKE TARE 7.75#. LENGTH BRAKE ARM 63" GAS PRESS. X "H₂O

RUN NO.	SPEED R.P.M.	GROSS LOAD #	BR. TARE #	NET LOAD #	T _{IN} H ₂ O °F	T _{OUT} H ₂ O °F	TORQUE LB.FT.	CORR. TORQUE LB.FT.	B. H. P.	B. H. P. CORR.
1	2200	10.75	7.75	3.00	155	184	15.75	16.3	6.6	6.83
2	2000	10.75		3.00		184	15.75	16.3	6.0	6.22
3	1800	10.75		3.00		184	15.75	16.3	5.4	5.60
4	1600	10.75		3.00		184	15.75	16.3	4.8	4.94
5	1400	10.75		3.00		184	15.75	16.3	4.2	4.36
6	1200	10.75		3.00		184	15.75	16.3	3.6	3.73
7	1000	10.75		3.00		184	15.75	16.3	3.0	3.11
8	800	10.75		3.00		184	15.75	16.3	2.4	2.48
9	600	10.75		3.00		184	15.75	16.3	1.8	1.87
10	400						15.75			
11										

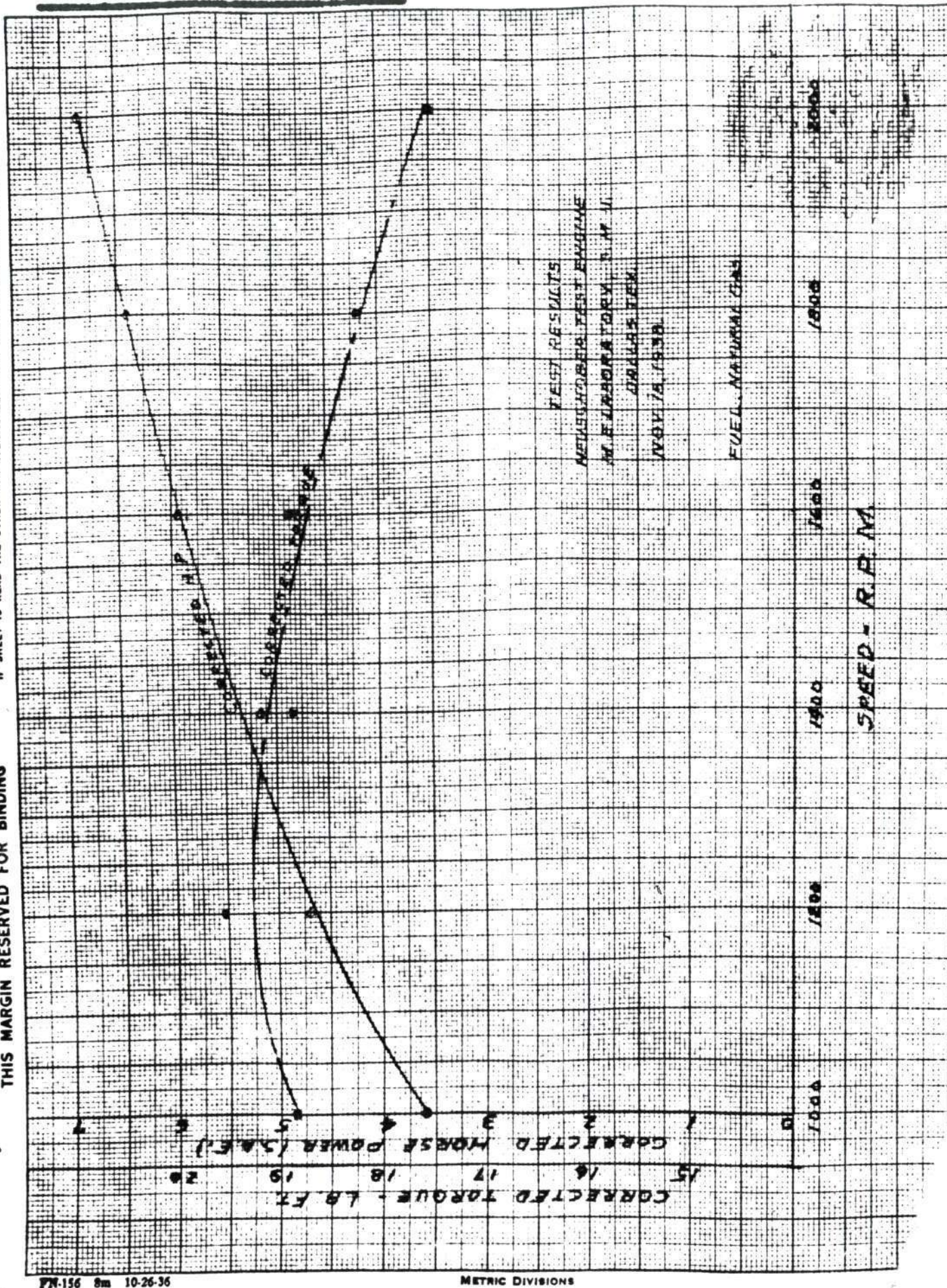
Correction for H.P. (S.A.E.)

$$= \frac{30 \sqrt{T_{ROOM}}}{P_{BAR} \sqrt{520}} = \frac{(30) \sqrt{542}}{(29.38) \sqrt{520}} = 1.036$$

Corrected H.P. = Actual H.P. x 1.036.

IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING



November 21, 1938.

Mr. E. E. Heuschober, President,
Heuschober Engineering Corporation,
2845 Eighth Avenue,
Fort Worth, Texas.

Dear sir,

I am enclosing herewith performance curves on the tests run last Friday in the Mechanical Engineering Laboratories at Southern Methodist University on the Heuschober Test Engine using Natural Gas as the fuel.

I would suggest that you compare these curves with those resulting from the tests run with Gasoline as the fuel. You will note that the Horse Power corrected in accordance with the S. A. E. Code shows a slight increase for Natural Gas over Gasoline at the lower and higher ranges of speed and marked increase at the intermediate points.

Both of these tests, though preliminary, seem to indicate the versatility of the Heuschober Principle and gives added force to my suggestion the Diesel Cycle application should be investigated when funds become available for the design and construction of an engine based upon the Diesel cycle.

Hoping that the enclosed will be of interest to you, I am,

Very truly yours,

Ray M. Watson, Head,
Department of Mechanical Engineering,
Southern Methodist University,
Dallas, Texas.

RMW/m.

November 18, 1938

Houder Test Engine $3\frac{1}{4} \times 3\frac{1}{4}$ Two Stroke Cycle
Brake Horse Power Test
Natural Gas

Noble Sherman

Room Temp 78°F Barometric Pres 29.30 Hg. Gas Pres $8^{\circ}\text{H}_2\text{O}$.

Brake Tor 7.75# Length of Brake Arm 63"

Run No.	P.P.M.	Water Temp Out	Gross Wt	Net Wt.	Corrected Torque	Brake HP	Corrected Brake HP
1	1000	160	11.25	3.50	18.85	3.50	3.58
2	1200	160	11.375	3.625	19.52	4.47	4.70
3	1400	161	11.25	3.50	18.85	4.90	5.15
4	1600	161	11.25	3.50	18.85	5.60	5.89
5	1800	161	11.125	3.375	18.19	6.08	6.40
6	2000	161	11.00	3.25	17.50	6.50	6.85

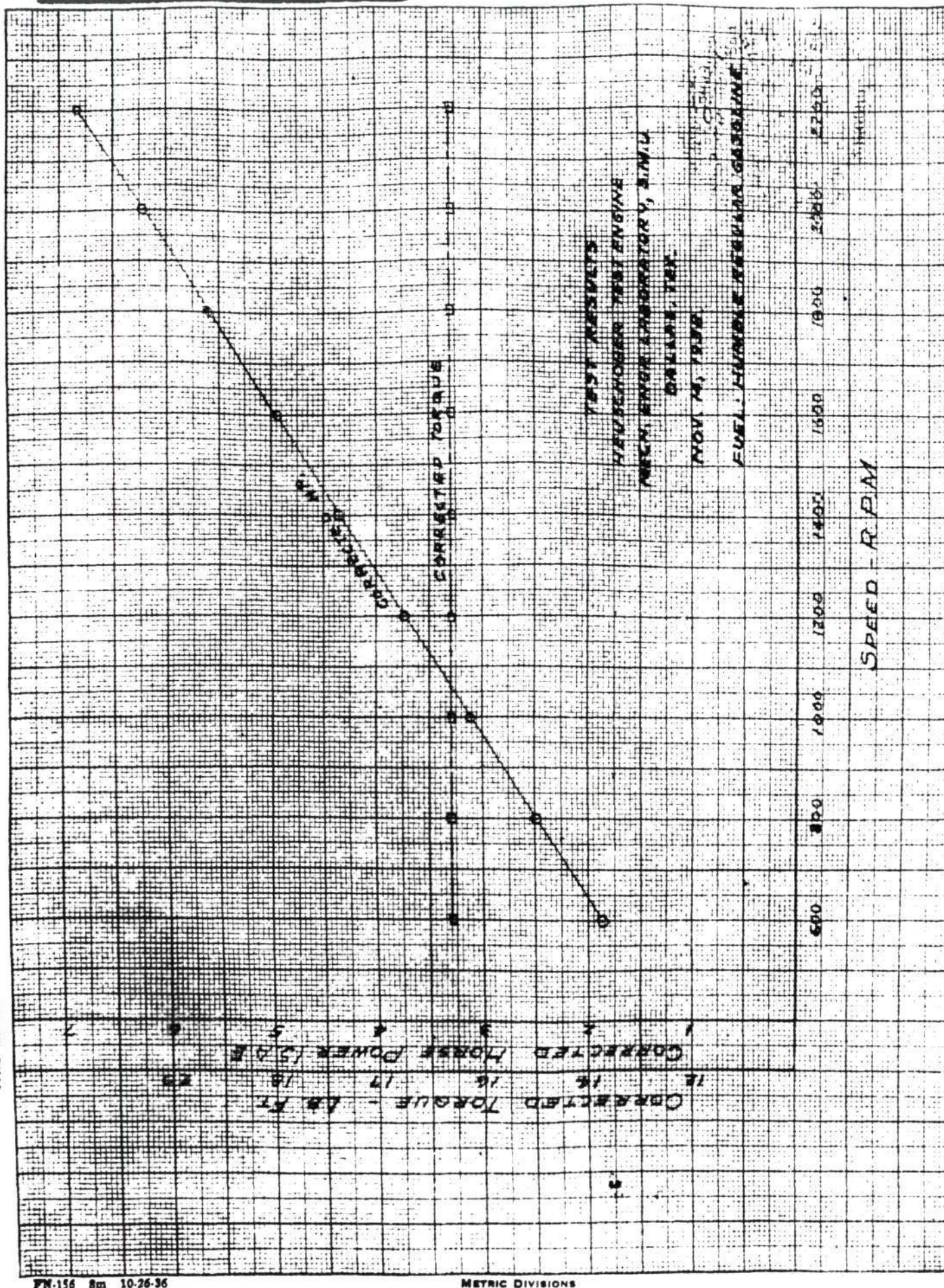
Corrected BHP to S.A.E. Standards

$$\text{Corrected HP} = \sqrt{\frac{\text{Room Temp. Abs}}{520}} \times \frac{30.00}{\text{Barometer Pres.}} \times \text{BHP}$$

$$\text{Corrected BHP} = \text{BHP} \times \sqrt{\frac{460+78}{520}} \times \frac{30.00}{29.30} = \text{BHP} \times 1.026.$$

IF SHEET IS READ THIS WAY (HORIZONTALLY) THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY) THIS MUST BE LEFT-HAND SIDE.

THIS MARGIN RESERVED FOR BINDING



adjustment cylinder was used to find a setting at which the performance was optimum. It was the opinion of the author that much more information of value could be gained by continuing the use of the devices which had been designed for the purpose of finding the proper port heights and by-pass chamber volumes for each speed.

Two sets of test data which were made during the test period are shown by photostats on Pages 62 and 65. The graphs showing performance curves for each of these tests are shown by photostats on Pages 63 and 66. Letters to the President of the Heuschober Engineering Corporation accompanying these graphs are shown by photostats on Pages 61 and 64. The testing work was slow since it was done at times which would not interfere with regular school duties.

The carburetor which was chosen for the test did not function with satisfaction. This was not entirely due to the design of the carburetor but rather to characteristics of the test engine. When the main piston commenced its compression and a low pressure developed in the inner piston chamber, the check valve responded quickly and the immediate suction on the carburetor line set the air-fuel mixture in sudden motion which pulled an over-rich mixture from the carburetor. The raw gasoline in this mixture settled out inside the by-pass chamber forming a pool by the end of each test run.

This situation influenced a change in test procedure. Until the proper type of carburetor to handle a liquid fuel could be found, all tests were made with natural gas. A comparison of the two sample tests, of which results are attached, shows a decided advantage with natural gas. The gas mixing valve was more easily controlled so that a proper mixture

of gas and air could be supplied. Since simplicity is of more importance than economy in a situation where the fuel is plentiful and inexpensive but access to repair parts is lacking, economy information was not stressed on all tests.

As stated above the tests were discontinued before the end of the year 1938 and a beginning made on a larger test engine to be used in the gas and oil fields. The study of this phase was made by Mr. Sherwood and was the basis of a thesis for a Professional Degree at the University of Kansas.

APPLICATION OF TEST ENGINE TO LAYOUT OF LUFKIN ENGINE

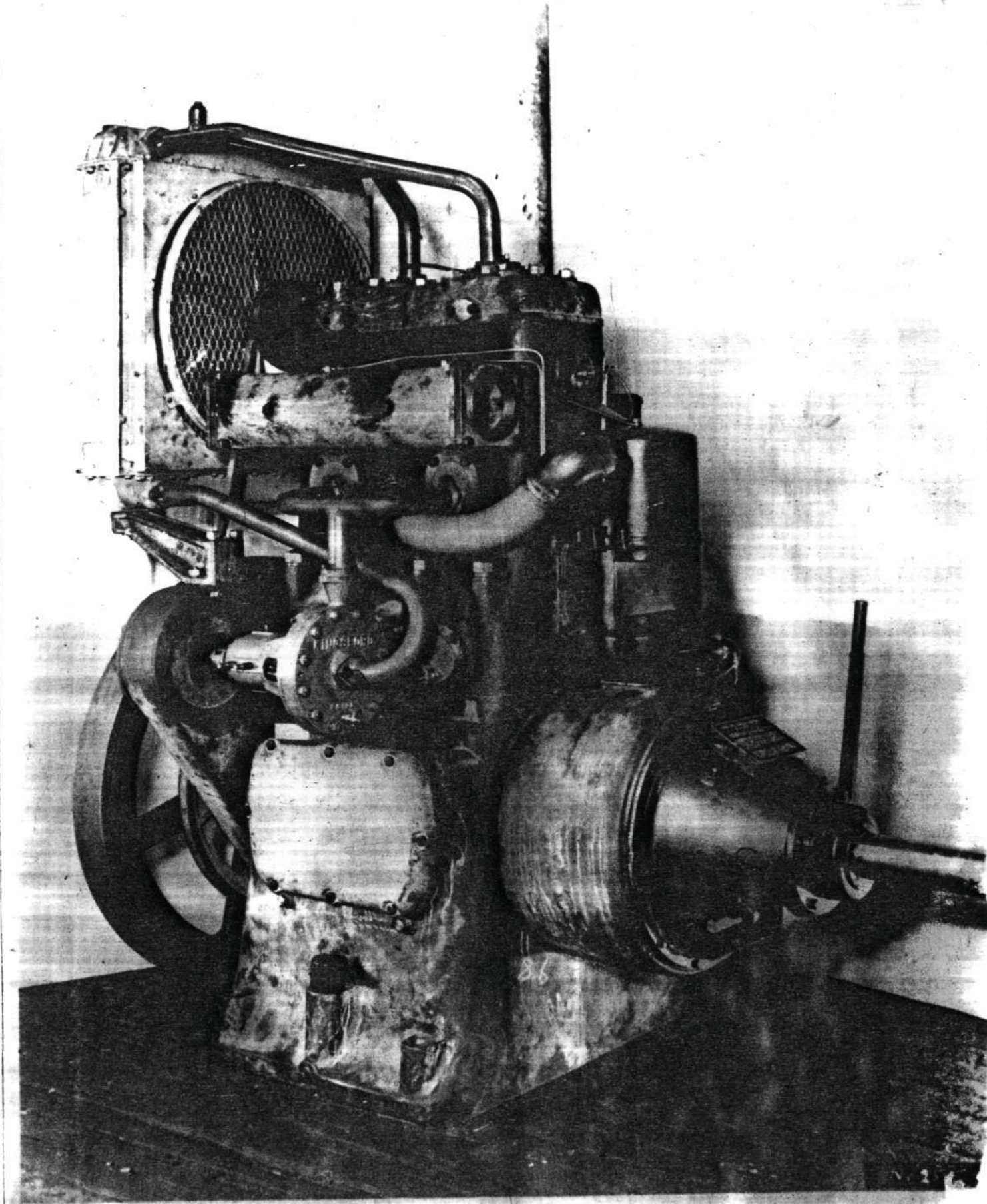
The test engine furnished not only a satisfactory proof of its principles to the board of directors of the Heuschober Engineering Corporation but also the basic design for the commercial engine developed for the Lufkin Foundry and Machine Works by Mr. Harold F. Shepherd.

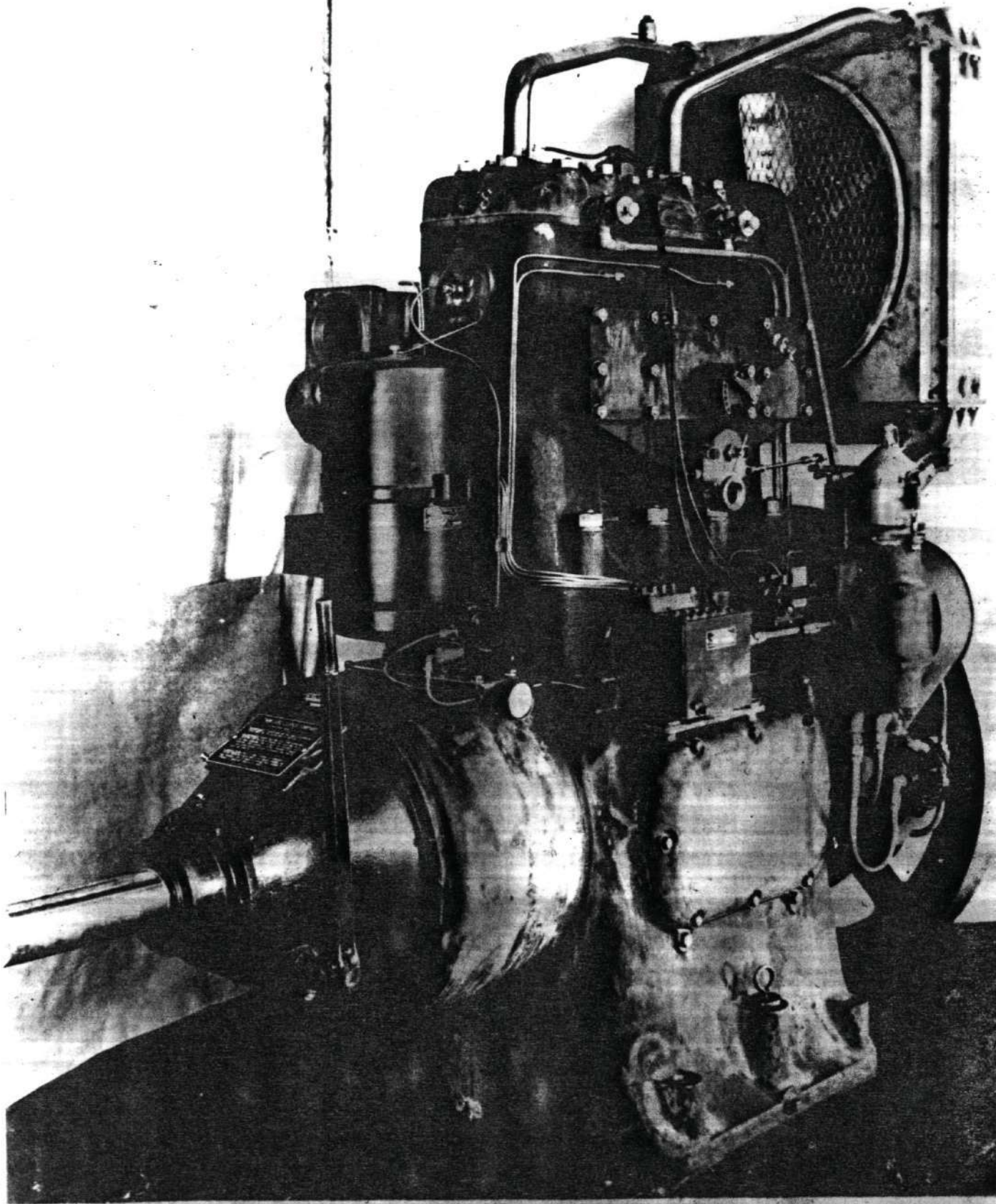
Two photographs of the Lufkin engine 1914-1915 are shown on Pages 70 and 71. This engine is a two cylinder two-stroke cycle unit. It has 7 3/4" bore and 9" stroke with a normal rating of 50 horsepower at 500 r.p.m. and a recommended maximum 60 horsepower at 600 r.p.m. The complete power unit, including clutch, water pump, radiator, air cleaner but without the sheave, weighs 5720 pounds. It was designed to operate either as a gas engine or, by changing to high compression heads and replacing the magneto with a fuel injection pump, as a full diesel. A vertical section of the engine is shown on the photostat, Page 72. A section drawing of the crankshaft is shown on the photostat, Page 73. An elevation is shown on the photostat, Page 74.

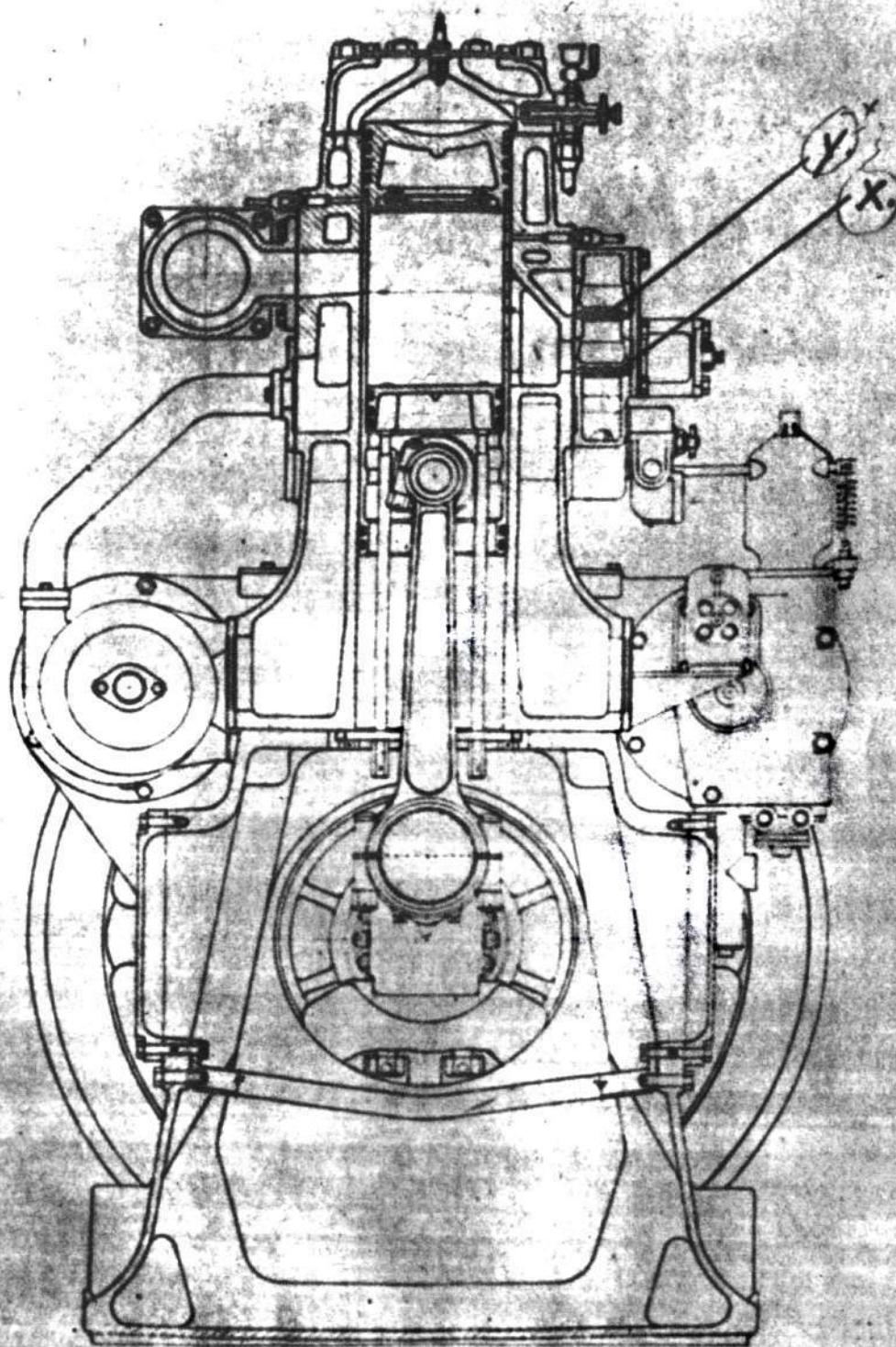
A comparison of these sections with the design sheets of the test engine indicates that the commercial development followed closely the design of its prototype. A number of variations, however, may be noted,

In order to utilize the Heuschober principle in the multi-cylinder engine, the following problems needed solution: intake from the by-pass chamber to the combustion chamber in one cylinder occurred simultaneously

"The Lufkin Engine for Oil Field and Industrial Service," a commercial booklet.





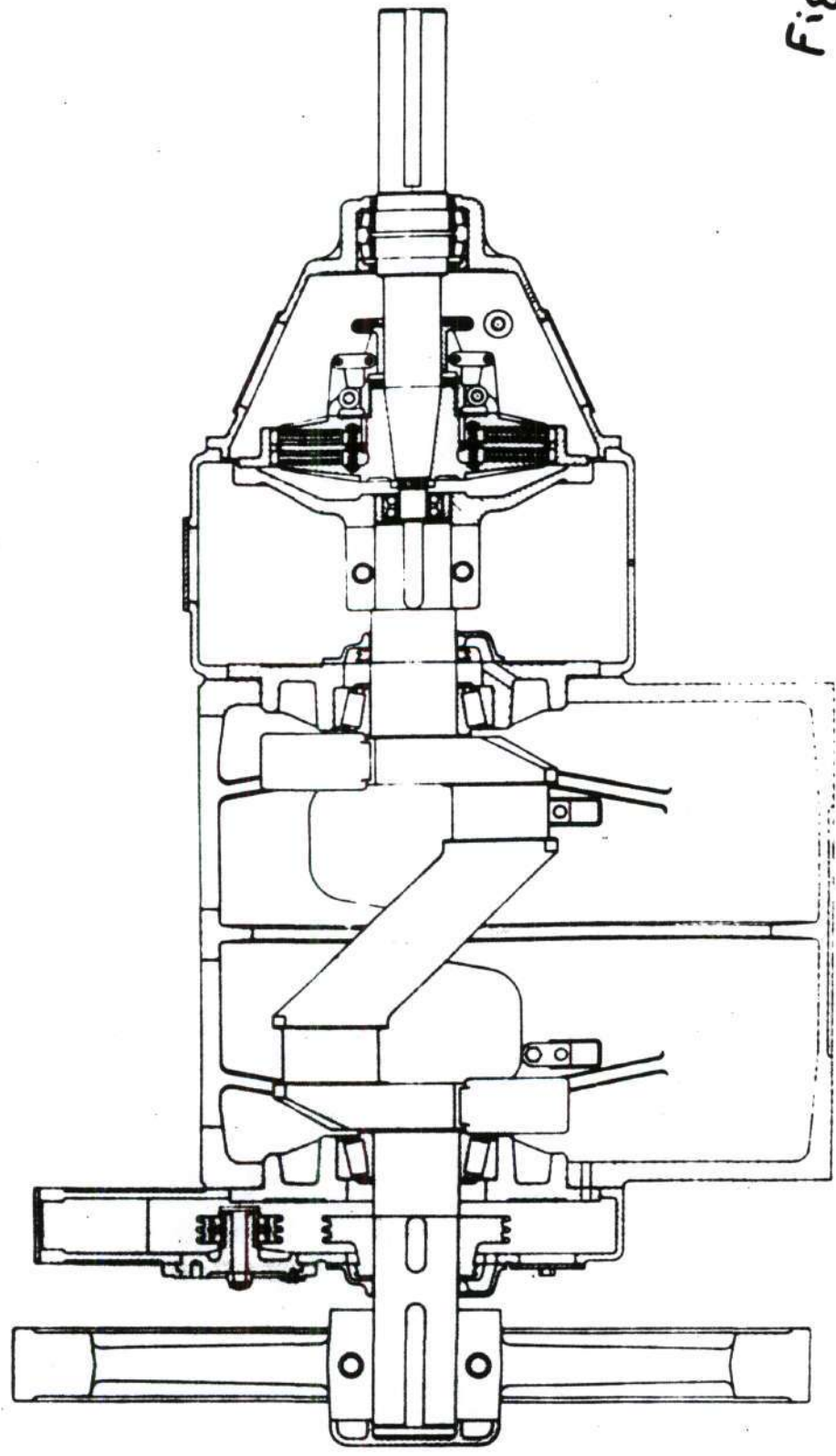


F

D

Vertical Section of Lufkin Engine 1914-1915.

Fig. B



Section of crankshaft of Lufkin engine 1914-1915.

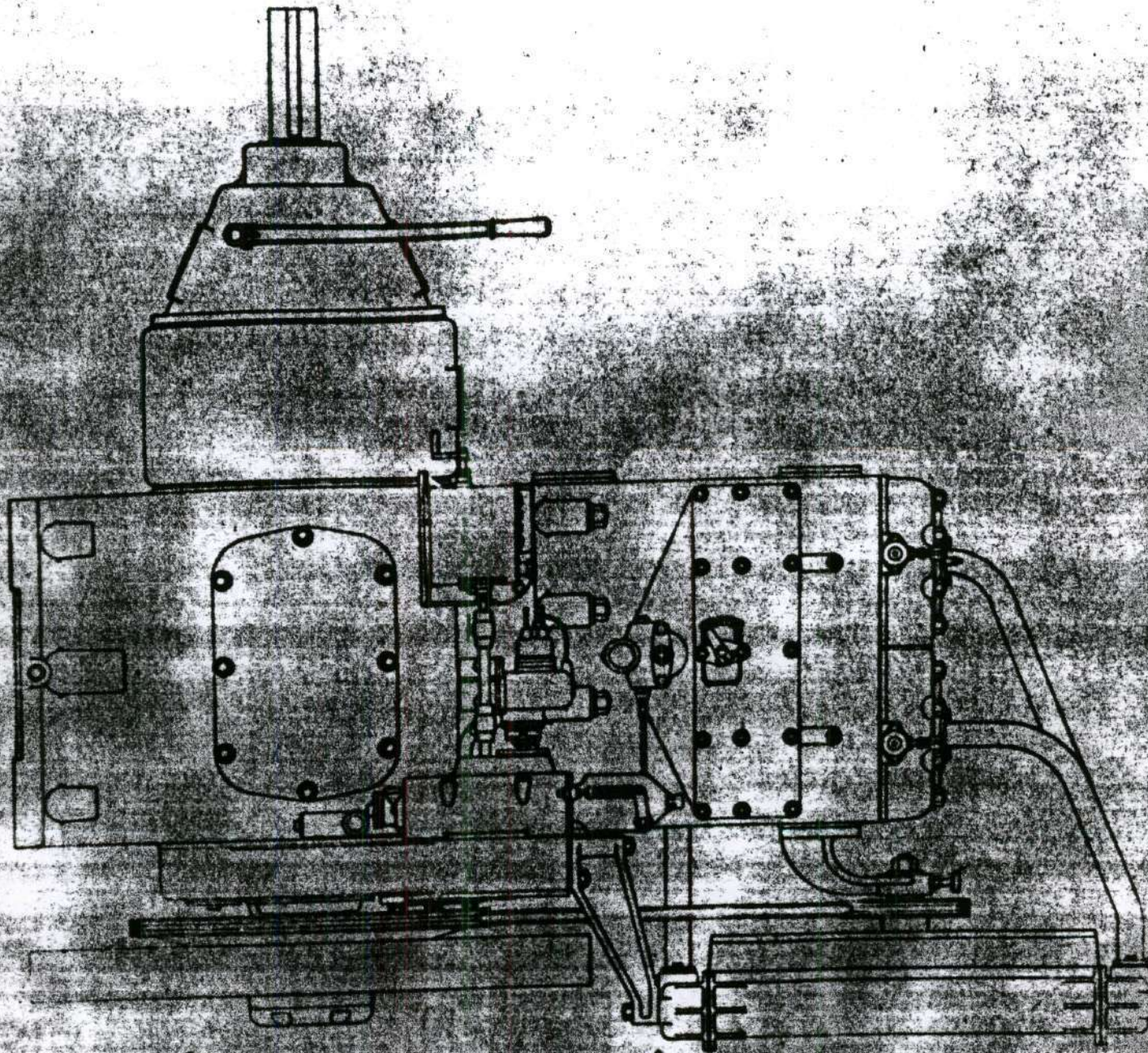


Fig C

with intake from the carburetor pipe into the by-pass chamber for the other cylinder. A design which was proposed to meet this situation is shown on the photostat, Page 76. In this the by-pass chamber is divided into two chambers. The lower one is connected directly to the carburetor intake and sealed from the other cylinder. The upper one is common to both cylinders. A rotary valve, to be externally operated, connected these chambers alternately with the inner cavity of the piston.

The solution adopted by Mr. Shepherd utilized two grid type valves which performed the desired function automatically. These are shown at "x" and "y" on Page 72.

The piston head design on the Lufkin engine is in accordance with Mr. Shepherd's own words in "Diesel Engine Design."

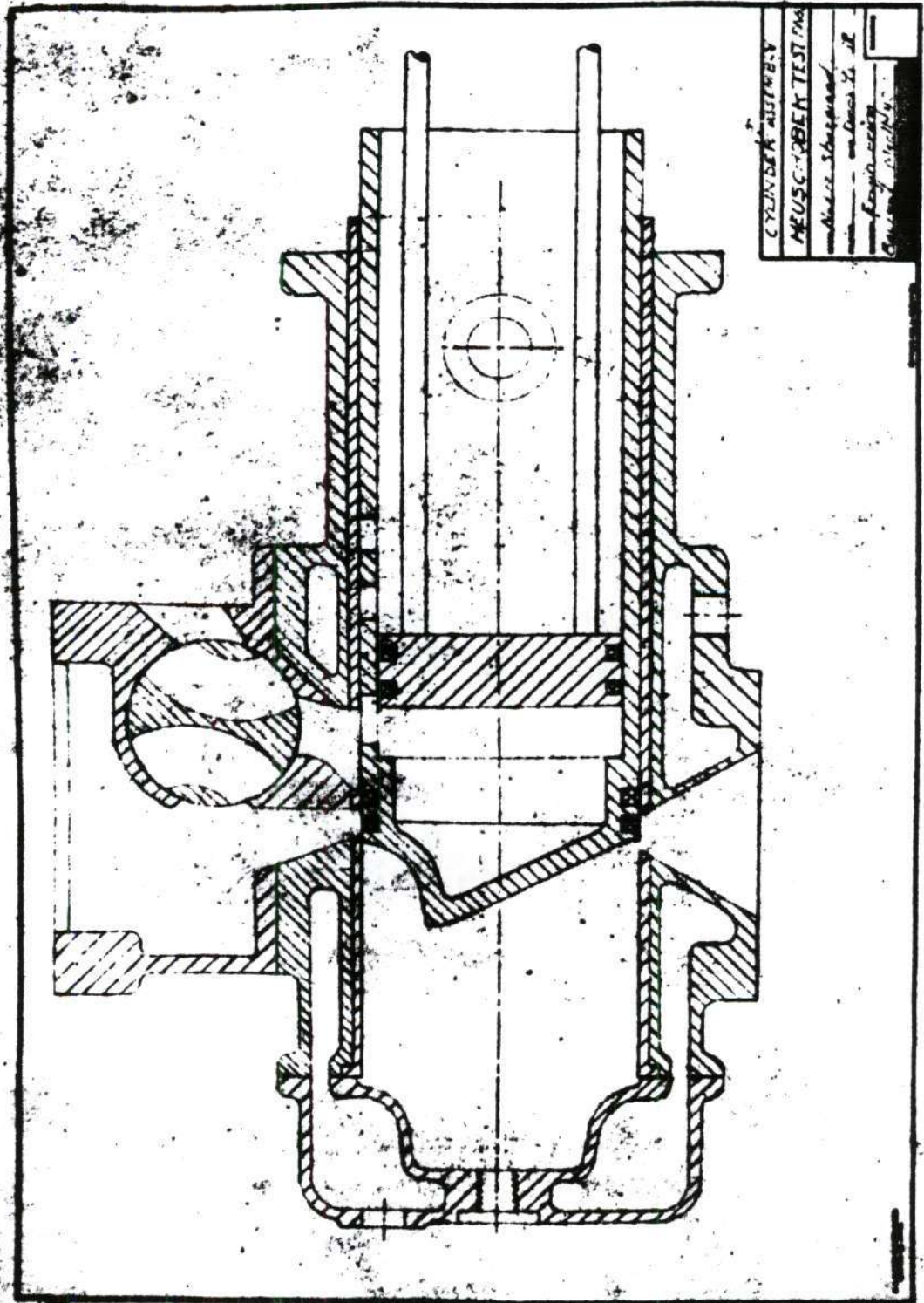
"Much ingenuity and more imaginative effort have been wasted on the profile of the deflector on the piston head. A simple arc of a radius equal to the inlet port length extended perhaps 10 percent by a straight line seems to serve as well as anything.

"If the deflector is used at all it is best to extend it all around the piston . . . to preserve the symmetry of the crown."

It is to be noted that the horsepower recommendation of the manufacturer as quoted above at given speeds indicate the same constant torque characteristics found in the test of November 18, 1938, Page 66.

The author received a solicited letter from Mr. John E. Catlin, Chief Production Engineer of the Shuler Unit of Lion Oil Company, Eldorado, Arkansas, which expresses favorable comment on the six Lufkin

Harold F. Shepherd, "Diesel Engine Design," 1935. pp. 122 and 123.



engines in operation. The photostat of this letter is on Page 78.

The repair of the second failure listed, a loose inner piston, was made possible by the method used on the test engine being retained on the commercial engine.

LION OIL REFINING COMPANY



EL DORADO, ARKANSAS

March 15, 1946

Mr. Ray M. Matson
Department Of Mechanical Engineering,
Southern Methodist University,
Dallas 5, Texas

Dear Mr. Matson:

In regards to your favor of February 28th. regarding the Lufkin engine. We are glad to furnish you with the following information, regarding our experience with this engine.

We are operating six 50HP twin cylinder vertical Lufkin engines that were put into operation 4-13-44, 5-29-44, 9-29-44, 11-4-44, 10-2-44 and 5-8-45 respectively. One of the engines broke a water pump coupling and was down 55 hours, while a new coupling was obtained from Lufkin Texas. On one of the other engines the inner piston came loose, requiring the engine to be down for 72 hours, while repair parts were obtained. Except for the afore mentioned instances the engines have operated continuously since installation.

We are using the Lufkin engines to power Lufkin TC-1A-54B pumping units. Pumping from an average depth of 6800 ft. Using 2 $\frac{1}{2}$ " tubing 4000 ft. of 3/4" and 2800 ft. of 7/8" sucker rods and 2 $\frac{1}{2}$ " x 1 $\frac{1}{2}$ " x 15' x 19 $\frac{1}{2}$ Axelson insert, liner type pumps. Pumping an average of 160 barrels of fluid per day.

The Lufkin engine compares very favorably with the type GSD Lufkin-Cooper-Bessemer engine, which we are also using.

Very truly yours,

LION OIL COMPANY

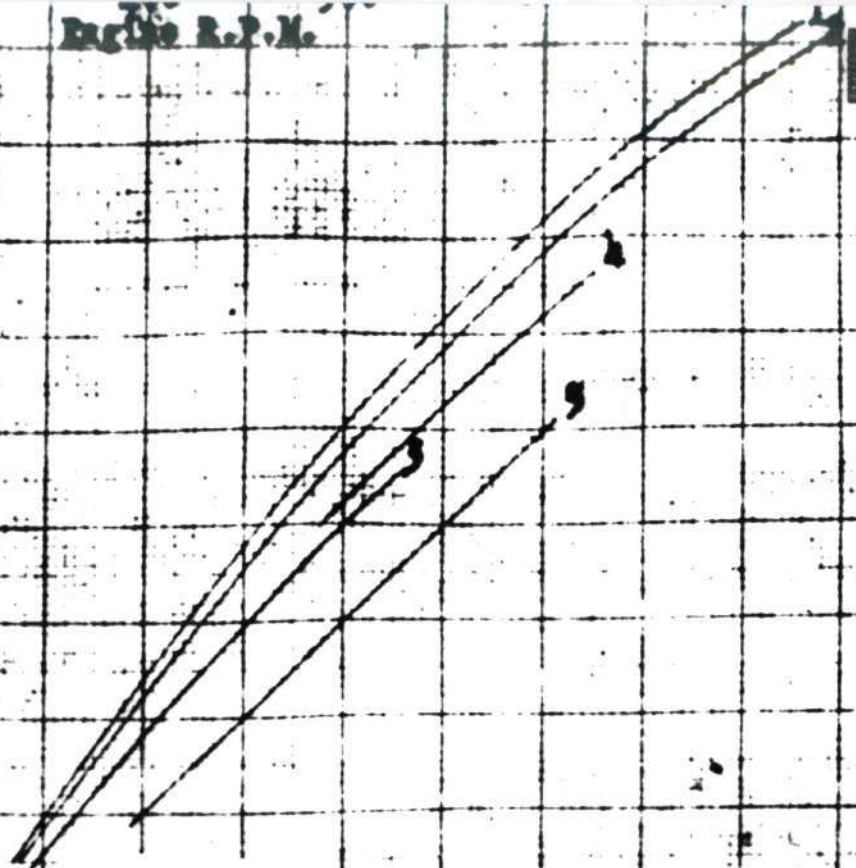
John E. Catlin, Shuler Unit
Chief Production Engineer

JEC/mb

ADDRESS ALL CORRESPONDENCE TO COMPANY

80
75
70
65
60
55
50
45
40
35
30
25
20

Brake Horse Power
at 40° F and 30" Hg.



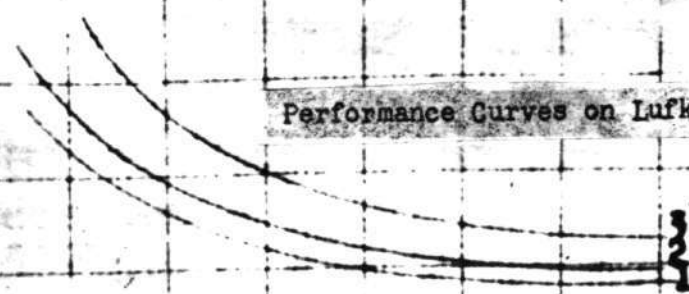
7-1/4 x 9-2 Cylinder Gas Engine
Fuel - Natural Gas 1054 BTU
per cu ft Higher Heat Value.

- Curves 1- Muffler Only
" 2- Muffler, Air Cleaner
and Water Pump
" 3- Muffler, Air Cleaner, Water Pump
and Radiator
" 5- Recommended Rating of Power Unit

NOTE:- Fan Pulley # 1 used to 500 R.P.M.
Fan Pulley # 2 used to 600 R.P.M.

3200
2800
2400
2000
1600
1200

B.T.U. per BHP Hr.
Lower Heat Value



Performance Curves on Lufkin Engine 1914-1915.

Brake Horse Power

Feb. 27, 1911

10 20 30 40 50 60

CONCLUSION

The term Engineer is quite difficult to define to the complete satisfaction of all concerned. Many artisans as well as charlatans have assumed the title and in many cases have been difficult to dislodge because of the lack of clarity in definition. The term Mechanical Engineer though still baffling, is much more easily defined on account of the narrowing of the field by the modifier, mechanical.

The definition which has been proposed by the author is a combination of other definitions proposed in the past few years.

A Mechanical Engineer is a person who applies the principles of the natural and social sciences to the natural resources at his command in order to design, produce, maintain and distribute or to supervise the design, production, maintenance and distribution by others of mechanical articles and services in order to satisfy the necessities, luxuries and whims of mankind.

The natural sciences which the Mechanical Engineer should apply include mathematics, physics, chemistry, and their various derivatives, such as mechanics, thermodynamics, metallurgy, hydraulics and electricity. Besides his mother tongue, some foreign language, psychology and public speaking, the social sciences, including economics, history, social studies and management, should fill a definite place in his kit of tools.

It is doubtful if a large number of persons could be found who would completely satisfy to a degree approaching perfection all of the above adjuncts. Certainly, the author cannot claim that distinction.

But he does feel that he can justify a sufficient approach to the ideals set forth by the above definition to merit the designation Mechanical Engineer.

The project, which is the subject of this paper, is the basis upon which the application for this distinction is supported.

The author received at the school which conferred upon him baccalaureate and master degrees a fundamental training in the basic subjects of mathematics, physics and chemistry, and their special applications in mechanics, heat power, materials of construction and electricity. In this institution and in Normal School, he completed satisfactorily all of the above social science and allied requirements with the exception of public speaking. This he gained in extra-curricular activities.

During the progress of the design of this project, the training in the field of the natural sciences was used in the choice of materials, their utilization in design of the elements, together with computations involving theoretical considerations and their modification to integrate the elements into a practical working whole. The principles of the invention imposed upon the work certain limiting conditions which called for some deviation from conventional designs. In the assembly and test periods of the project, extreme care was required in dealing with conditions differing from those encountered in conventional equipment. Economic restrictions called for substitutions which would not exist in research work backed by less limited resources.

Practical psychology played an important part in this project. It would have been quite easy to disrupt the cordial relations which

were maintained during the design period by assuming the attitude that the engineer is always right and that the untutored should accept whatever he proffered without receiving a reasonable explanation. Instead, the author gave a respectful hearing to all suggestions of the inventor and his associates and made a sincere attempt to furnish them with logical explanations for procedures in question. A similar attitude was found useful in dealing with the various mechanics and helpers, and paid dividends in gaining the interest of these workers in the project.

As this frankness continued throughout the conferences of the design period, the inventor, at least, came to a feeling that the engineers had some reasonable bases for their designs. Mr. Sherwood and the author had initially decided that controversial matters should be worked out agreeably whenever possible before bringing the others into discussions. This arrangement strengthened the position of the engineers with the others. Subsequent consulting work can be attributed to the confidence instilled by the above policy.

As outlined in a previous section of this paper, the author was called upon to appear before the sessions of the board of directors and of the stockholders of the Heuschober Engineering Corporation and present the progress of the project. Practical experience in public speaking and study of the types of individuals who composed these two bodies combined to make this function acceptable.

The experience of the author in this project and others leaves him with the firm conviction that a Mechanical Engineer should continually strive to increase his scope of interests and breadth of vision.

Only in this manner may he hope to serve in the expanded functions of the Mechanical Engineer.

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